# Technical Appendix

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**EXHIBIT B**

## SUMMARY

This Technical Appendix reviews the support NTIA puts forward for its determinations regarding compatibility of GPS receivers and the feasibility of various mitigation strategies, primarily focusing on its adverse determinations regarding personal/general navigation and FAA-certified aviation devices.

As discussed in more detail below and in Exhibit A, the evidence is overwhelming that the testing and analysis of personal/general navigation devices failed to comply with widely-accepted, reasonable standards and failed to reflect LightSquared's stated deployment plans, with the result that the tests cannot be used to support any rational conclusion regarding the general population of such devices.

In addition to many flaws in the tests themselves, the analysis of the test results was based on an obsolete model of LightSquared's deployment plan. If NTIA had given proper consideration to LightSquared's proposal for deployment, it would have concluded that over 80 percent of the devices tested passed even the unreasonable 1 dB $C/N_0$ test that NTIA imposed. Accounting for yet other flaws in the tests and analysis would result in potentially all of the personal/general navigation devices "passing."

At the time the NPEF report was issued, LightSquared had agreed both to reduce the maximum power of its base stations as a function of their height and to guarantee not to exceed a given power on the ground at the location of practically any GPS receiver. The guarantee to a limited power on the ground would be provided either by: (i) designing and deploying the network based on the use of a light-clutter propagation model or (ii) using a post-deployment measurement program with sufficient spatial resolution to identify any hotspots that would be eliminated by further modification of base station power. NPEF failed to credit these commitments in its tests and NTIA, in its letter to the FCC, fails to either acknowledge LightSquared's proposals or address them in its consideration of mitigation options.

Similarly, with respect to aviation devices, as discussed below and in more detail in Exhibit B, the evidence shows that mitigation proposals were rejected before FAA requirements were even established or feasible mitigation proposals could even be considered.

Exhibit C of the Technical Appendix discusses a key technical issue that NTIA neglects to analyze or credit, despite its importance: the ability of GPS manufacturers to build receivers that are compatible with LightSquared operations without any loss in performance or material increase in cost or size. NTIA fails to note that all classes of GPS devices include at least some devices that, as manufactured and without modification, pass even the flawed process by which NTIA judges them. Exhibit C rebuts the various technical arguments that commercial GPS manufacturers have made that high performance capabilities require GPS devices to be incompatible with LightSquared's operation and shows that there is no reason why all GPS devices could not have been designed and built to be compatible with LightSquared operations.

## EXHIBIT A

## NTIA'S CONCLUSIONS REGARDING PERSONAL/GENERAL NAVIGATION DEVICES ARE NOT SCIENTIFICALLY VALID

This exhibit evaluates the National Telecommunication and Information Administration's (NTIA) testing and analysis[1] of potential overload of personal/general navigation devices in proximity to LightSquared base stations and concludes that there were major flaws in both the tests and the analysis. The failures in the test process, which are described in Section I, include a biased device selection process, shoddy test practices, and woefully incomplete data collection and presentation, among other things. Section II describes major failures in the analysis of the test data involving the use of the wrong power level for the LightSquared signal. Section III focuses on the improper use of a loss of 1 dB $C/N_0$ as the measure of overload, despite the absence of any evidence that such a loss provides any meaningful indication of loss of position accuracy or any other significant impact on the end-user experience.[2]

As discussed further in Section IV, when the results are normalized to account for the more obvious failures in the testing and analysis, it is apparent that none of the devices tested is incompatible with LightSquared's operations. Most of the devices would have passed even the flawed 1 dB $C/N_0$ threshold if NTIA had used -30 dBm for the power at the receiver, instead of the -15 dBm level in its analysis. An additional nine devices would have passed if NTIA had used a more appropriate level of 6 dB $C/N_0$ as its pass/fail criterion. (LightSquared does not accept that even this is an appropriate method to determine loss of position accuracy, but it is more reasonable than a 1 dB loss.) Still more would have passed if NTIA had recognized the impact of LightSquared operating with Left Hand Circularly Polarized antennas. Moreover, many of the devices that "failed" appear to have been improperly included in the testing, either because they were high-precision devices, incomplete devices (i.e., subsystems or modules), or cellular devices. On top of that, many of the test results showing "failure" should be discarded based on irregularities in their testing, represented by either unexplained inconsistent results or an abnormally low quiescent $C/N_0$ that suggests the antenna was mis-oriented or the device was malfunctioning.

Attachment A-1 describes why NTIA's concerns about potential overload from LightSquared user devices are unfounded.

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1 Also hereinafter referred to as the National Space-Based Positioning, Navigation, and Timing Systems Engineering Forum (NPEF) tests or testing.

2 According to NPEF, Idaho National Labs reviewed the testing requirements and test set-up and observed the test execution and data collection and MIT Lincoln Laboratory reviewed the testing methods and findings. National Space-Based Positioning, Navigation, and Timing Systems Engineering Forum (NPEF), Follow-on Assessment of LightSquared Ancillary Terrestrial Component Effects on GPS Receivers, at 3 (January 6, 2012) ("NPEF Report [1]").Both entities prepared reports that NPEF cites in support of its process and findings. NPEF Report [1], at 3. LightSquared, however, despite its requests, so far has been denied access to these reports.

## I. NTIA RELIED ON TESTS THAT WERE NOT PROPERLY DESIGNED OR CONDUCTED

All told, the NPEF tests deviated from internationally accepted testing standards[3] in a number of critical ways, including the following:

- The process for selecting devices was deeply flawed and biased the outcome.
    - NPEF failed to establish any clear criteria for selecting devices.
    - Instead of a well considered plan for obtaining a representative sample of the total population of general navigation GPS devices, participants, including vendors that opposed LightSquared, were simply invited to bring and test whichever devices they wished.
    - Many of the devices included in the tests and the reported results do not appear to qualify as general navigation receivers.
    - No effort was made to determine whether the models tested were widely sold or in use.
    - Some of the devices were not production units.
    - The devices were not pretested to validate that they were operating correctly and had not been modified.

- Critical variables were not controlled during the tests, including the antenna orientation and spacing of devices, and partisan participants were allowed to modify devices during testing.

- The tests produced a large amount of data showing problems with the tests' validity; these problems should have been examined and explained:
    - There is unexplained and inconsistent data for the same devices tested by both the Technical Working Group (TWG) and NPEF;
    - There is unexplained and inconsistent data for the same device from just the NPEF tests, including missing blocks of data and abnormal behavior of $C/N_0$ during the tests; and

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3 The evaluation focuses on two international standards for test laboratory practices and coexistence analysis:

(i) ISO/IEC 17025:2005, "General requirements for the competence of testing and calibration laboratories" ("ISO 17025 [12]") and

(ii) IEEE 1900.2:2008, "IEEE Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems" ("IEEE 1900.2 [13]").

ISO 17025 [12] is the internationally recognized standard for laboratory practice. Accreditation to ISO 17025 [12] is required of laboratories that perform regulatory compliance tests by many agencies, including the FCC. The principles contained in ISO 17025 [12] apply to labs generally but also to specific testing efforts, which is how the standard is applied here.

IEEE 1900.2 [13] was written specifically to guide a coexistence analysis, such as this. It was developed to make coexistence analysis more objective and supportive of innovation and improved use of the spectrum.

- There is a much greater variation of quiescent $C/N_0$ (without LightSquared signals) among different devices than would be expected from the device locations on the test bench.

- Key data was not reported by the participants to NPEF and by NPEF to LightSquared and the public; the availability of this data is critical for a transparent process that permits public review and independent validation of the tests and their results.

- NPEF's analysis does not properly account for environmental noise.

**A. The selection process failed to even attempt to identify a representative or otherwise qualified sample of devices**

For the purposes of this testing, NPEF should have established a sampling plan in order to understand the potential impact to the mainstream population of general navigation receivers. Some of the device selection criteria should have been: (i) whether the device was a mainstream Personal/General Navigation device in commercial use; (ii) whether the devices were still in production; (iii) the current market share of the device; and (iv) the likelihood of the device being used near a LightSquared base station.

In contrast, NPEF did not establish any objective baseline criteria for selection of testing devices or provide information about the models tested in its Report. In the Report, NPEF states that "[d]ue to the time constraints for test completion, the NPEF did not limit federal or commercial participants' requested receivers from participating in the testing. In addition . . . other receivers were tested (at each participating organization's discretion)."[4] It seems contradictory to allow unlimited submission of devices due to time constraints on the testing. One would expect just the opposite, that if test time was limited, device selection would have been done with great care to make best use of the time and ensure that the devices tested best represented the population of devices in use. But the government entities and GPS manufacturers participating in the tests were able to include any device(s) of their choosing in the tests.

Many of the devices categorized as Personal/General Navigation devices appear not to qualify as devices sold to the general public. Fourteen of the "devices" were not actually complete GPS devices at all, but were GPS modules and evaluation kits intended as components of completed devices.[5] The performance of those devices would have been affected by the antenna and other essential RF components added to the module. Four devices were cell phones or other devices that did not qualify as Personal/General Navigation devices.[6] Finally, two of the devices tested are high precision devices.[7] Some of the devices tested also appear to be targeted to niche markets, such as hiking or boating, that are unlikely to be used near LightSquared base stations.

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[4] NPEF Report [1], at 3.

[5] Those devices were device numbers 247, 235, 333, 360, 232, 105, 307, 204, 383, 327, 127, 395, 322, and 373.

[6] Those devices were device numbers 102, 315, 377, and 398.

[7] Those devices were device numbers 350 and 341.

Because the report provides no further details about the device characteristics, there is no evidence of whether the devices tested are in current use (as opposed to out-of-date models), their intended use, or how many devices have been sold.

The sample of devices tested was non-conformant to ISO 17025 [12], subclause 5.7, sampling:

> ***5.7 Sampling***
>
> ***5.7.1*** The laboratory shall have a sampling plan and procedures for sampling when it carries out sampling of substances, materials or products for subsequent testing or calibration. The sampling plan as well as the sampling procedure shall be available at the location where sampling is undertaken. Sampling plans shall, whenever reasonable, be based on appropriate statistical methods. The sampling process shall address the factors to be controlled to ensure the validity of the test and calibration results.

### B. Samples were not properly controlled and participants were allowed to modify devices

In addition to ceding control of the selection process to participants, NPEF also put participants in charge of test set-up. According to the report, test participants were "entirely responsible for setup and data recording."[8] "Few constraints were placed on the data collection process" other than the use of standardized data messages to support "automated data reduction and presentation."[9]

In fact, according to a LightSquared observer, participants had near-total command over device set-up and configuration and the recording of data.[10] The vendors monitored their own devices, gathered performance data and delivered a subset of that data, the 1 dB $C/N_0$ values, to the Air Force's laboratory staff. There were few controls for critical testing elements such as antenna configuration and orientation. All of this is contrary to ISO 17025 [12]:

> ***5.8 Handling of test and calibration items***
>
> ***5.8.1*** The laboratory shall have procedures for the transportation, receipt, handling, protection, storage, retention and/or disposal of test and/or calibration items, including all provisions necessary to protect the integrity of the test or calibration item, and to protect the interests of the laboratory and the customer.
>
> ***5.8.2*** The laboratory shall have a system for identifying test and/or calibration items. The identification shall be retained throughout the life of the item in the laboratory. The system shall be designed and operated so as to ensure that items cannot be confused physically or when referred to in records or other documents. The system shall, if appropriate, accommodate a sub-division of groups of items and the transfer of items within and from the laboratory.

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8 NPEF Report [1], at 26; *see also* NPEF Report [1], at 9.

9 NPEF Report [1], at 26.

10 *See* Declaration of Steve Holley, Attachment A-2.

> ***5.8.3*** Upon receipt of the test or calibration item, abnormalities or departures from normal or specified conditions, as described in the test or calibration method, shall be recorded. When there is doubt as to the suitability of an item for test or calibration, or when an item does not conform to the description provided, or the test or calibration required is not specified in sufficient detail, the laboratory shall consult the customer for further instructions before proceeding and shall record the discussion.

NPEF has also provided no records of the actions performed by the participants and no certifications from participants or the Test Director that devices were not materially altered between tests. This is clearly in violation of ISO 17025 [12], subclause 5.3.4:

> ***5.3.4*** Access to and use of areas affecting the quality of the tests and/or calibrations shall be controlled. The laboratory shall determine the extent of control based on its particular circumstances.

The Report claims that "[n]o access to the antenna farm was permitted during the test events to ensure the test setup was not impacted . . . In between test events some access to the antenna farm was granted under the supervision of the Test Director to restart devices, log data files, and replace batteries."[11] This is contradicted, however, by a LightSquared observer, who saw what appeared to be the modification, reorientation, and replacement of at least one device antenna.[12]

A number of critical variables were not recorded or controlled during the testing. The potential for the devices to affect each other was not sufficiently checked.[13] It appears from Figure A.I.1 below, taken from the NPEF Report [1], that some devices were spaced more closely than provided in the plan, which may have been close enough so as to degrade each other's performance, either by their emissions or coupling between devices. This is in contrast to the plan used by CTIA for testing cellular devices, which directs:

> A test site shall provide at least the specified minimum measurement distance for all tests and validation procedures described in this test plan. Alternatively, a minimum measurement distance of 1.2 m may be used, provided the appropriate uncertainty term is included in the uncertainty budget for the test case.[14]

With respect to orientation of the device antennas, rather than establishing defined positions and antenna orientations, the NPEF tests "assumed that the participants configured their systems and antenna such that their receivers were operating in a typical manner."[15] The NPEF Report [1] does not cite any measures that were taken to communicate that expectation to government and commercial test participants, or to confirm the veracity of that assumption. It

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[11] NPEF Report [1], at 27.

[12] *See* Declaration of Steve Holley, Attachment A-2.

[13] *See* Declaration of Steve Holley, Attachment A-2. Although a "sniff" test was performed before testing began, it was not repeated before individual test events. Nor was there any testing for "coupling" of devices.

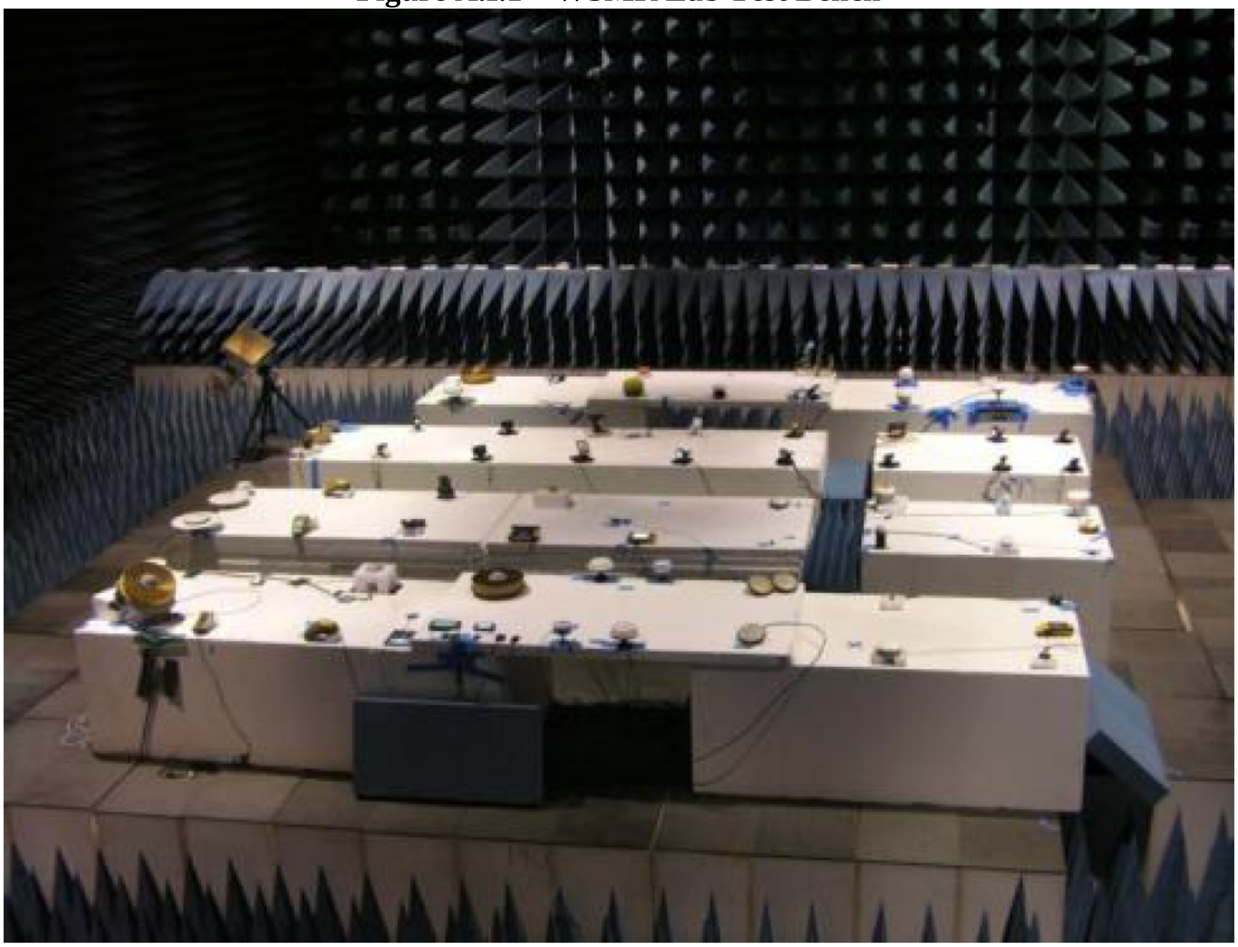
[14] CTIA Certification Test Plan for Mobile Station Over the Air Performance, Rev. 3.1, at p. 34 (January 2011) ("CTIA Test Plan [2]").

[15] NPEF Report [1], at p. 25; *see also* NPEF Report [1] at p. 26.

therefore cannot be concluded that systems and antennas, in fact, were set up to operate as they would in a real world environment.

In fact, Figure A.I.1 actually shows that many devices were oriented so that the peak of the antenna pattern was pointed at the base station antenna, whereas during typical operations most GPS receivers would encounter the LightSquared base station signal at an angle of approximately 10 degrees at the point of greatest power on the ground.[16] The selective orientation of the boresight of the antenna towards the base station antenna, which was at a nominal elevation of $20^0$ relative to the test bench, also reduced the antenna gain towards the GPS signal radiator, which was at an elevation of $90^0$ (directly overhead). These material deviations are not explained and together could account for 3-6 dB greater interference/signal ratio than would be normally encountered.

**Figure A.I.1 – WSMR Lab Test Bench**



These factors and others bring into question conformance with ISO 17025 [12], subclause 5.4.2:

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[16] This follows from the path geometry, given a typical antenna height of 30 m and LightSquared's base station antenna pattern. The elevation angle to the GPS receiver is not a strong function of the base station antenna height between 15 m and 50 m.

***5.4.2 Selection of methods***

> The laboratory shall use test and/or calibration methods, including methods for sampling, … which are appropriate for the tests and/or calibrations it undertakes.

ISO 17025 [12] further direction in subclause 5.4.2:

> The laboratory shall confirm that it can properly operate standard methods before introducing the tests or calibrations. If the standard method changes, the confirmation shall be repeated.

It is the laboratory's responsibility to ensure that it is properly equipped to handle the testing being requested. In this case, it appears that the chamber used was not equipped with automated devices for positioning the equipment under test, resulting in lack of control over critical variables. Anechoic chambers that evaluate a device's performance with appropriate automation to control relative positioning in three dimensions are commonly available. In fact such a chamber was used for both the TWG and the recent NTIA-sponsored cellular testing. In that case, each device was characterized for its three dimensional antenna performance, as an early step in the testing process. If the anechoic chamber initially selected for this testing was inadequate then another, qualified, chamber should have been used so that the testing could be performed properly, given its important purpose.

In the context of non-standard tests such as these, it is particularly important to validate that the methods selected are correct for the purpose and will provide objective evidence of device performance. ISO 17025 [12] requires:

***5.4.5 Validation of methods***

> ***5.4.5.1*** Validation is the confirmation by examination and the provision of objective evidence that the particular requirements for a specific intended use are fulfilled.

> ***5.4.5.2*** The laboratory shall validate non-standard methods, laboratory-designed/developed methods, standard methods used outside their intended scope, and amplifications and modifications of standard methods to confirm that the methods are fit for the intended use. The validation shall be as extensive as is necessary to meet the needs of the given application or field of application. The laboratory shall record the results obtained, the procedure used for the validation, and a statement as to whether the method is fit for the intended use.

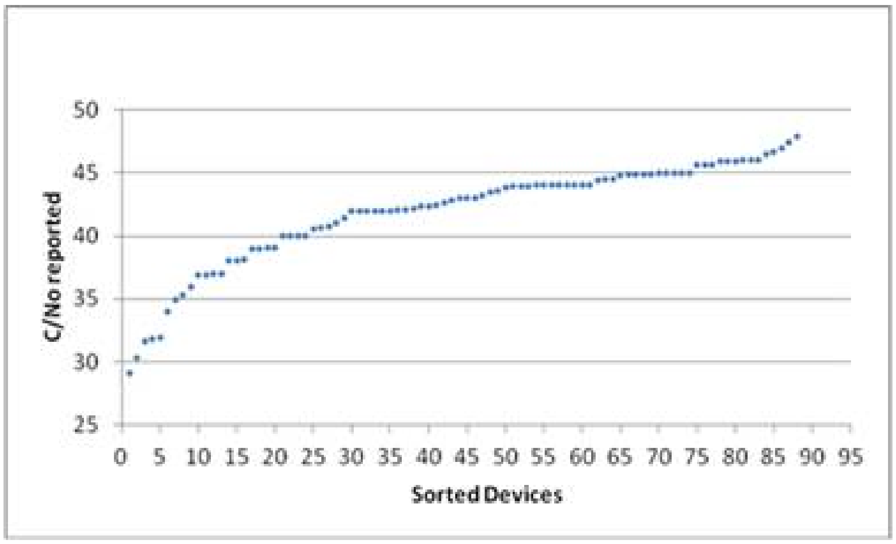
> ***5.4.5.3*** The range and accuracy of the values obtainable from validated methods (e.g. the uncertainty of the results, detection limit, selectivity of the method, linearity, limit of repeatability and/or reproducibility, robustness against external influences and/or cross-sensitivity against interference from the matrix of the sample/test object), as assessed for the intended use, shall be relevant to the customers' needs.

As discussed above, NPEF seems to have ignored this requirement. There is no evidence of the stability and repeatability of the testing performed or its correlation to field performance.

### C. Inconsistent data should have triggered further examination of the test data

One of the most troubling aspects of the testing is the failure to recognize or account for various inconsistencies that should have been "red flags" that the tests were not producing reliable results. A prime example of this is the variation in quiescent $C/N_0$, the measurement of the carrier-to-noise ratio without any LightSquared signal or potential for overload, as shown in Figure A.I.2.

**Figure A.I.2 - Variation of Quiescent $C/N_0$ reported by GLN devices (value reported in the absence of LightSquared signals)**




The $C/N_0$ that should be reported by a device is a predictable quantity, if the incident GPS signal power, antenna gain and noise figure are known. The relationship is given by

$C/N_0$ (dB.Hz) = GPS_signal_power_in_isotropic_antenna (dBm) + antenna_gain – receiver_noise_figure (dB) + thermal_noise_PSD (dB.Hz)

Assuming typical values

44.5 dB.Hz = -128.5 dBm + 3 – 4 dB + 174 dB.Hz

According to NPEF Report [1], the test bench was calibrated to provide a nominal, time-invariant GPS signal level of -128.5 dBm for L1 C/A code signals, measured with a 0 dBi reference antenna, for all satellites.[17] There was approximately 5 dB variation as a result of the locations of the receiver on the test bench having different distances from the GPS transmit antenna on the roof. As described in the Report, $C/N_0$, referenced to a 0 dBi antenna, was

[17] NPEF Report [1], at Appendix E.2. The P code signal was 3 dB lower but is not relevant to a discussion on GLN devices.

expected to be between 42 and 47 dB.Hz. As part of the NPEF calibration process, the $C/N_0$ was verified by measurements on two receivers and conformed to this expectation. Yet, in Figure A.I.2 above, variability between devices is between 28 and 47 dB.Hz – a range of 19 dB. While up to a 5 dB variation may be attributed to the location of the receiver and perhaps as much as 3 dB to variations in antenna gain and noise figure, there is still an unexplained variation of approximately 11 dB. This may have been because of (i) the deliberate and arbitrary orientating of the devices practiced by the manufacturers to maximize the response towards the base station antenna, and in the process reducing the gain towards the GPS signals, (ii) a fundamental flaw in the calibration of the test set up or (iii) a device was damaged, modified or for some other reason not operating properly, or all of these reasons.

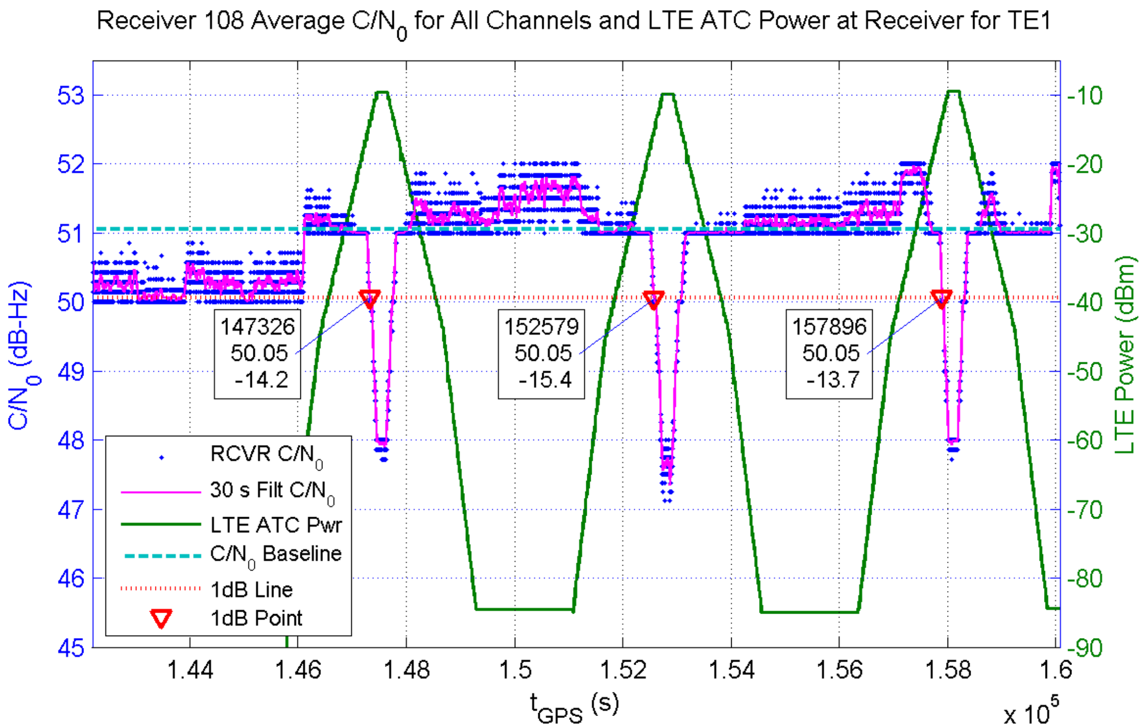
Regardless of the cause, when abnormally low values of $C/N_0$ were observed during the initial test set up, the testing should not have commenced until the $C/N_0$ values reached predictable levels and devices gave stable readings in the test setup with only the GPS signal present. Some of the quiescent $C/N_0$ levels are so low that it is questionable whether the receivers were consistently in lock during the tests.

A closer look at the individual test events reveals other troubling anomalies and holes in the data which should have served as "red flags" and which NPEF did not attempt to explain in its report. These data are described below.

### 1. Receiver 108 in TE1

In the highlighted plot from Test Event 1, Receiver 108 starts logging in the absence of LTE power, but does not report C/No at the expected baseline levels prior to the introduction of the LTE interferer. An abrupt change in the C/No values can be observed just at the start of the test. Clearly something changed but what changed is not reported. After the LTE interferer is started, Receiver 108's C/No starts reporting at the expected levels prior to degrading. For the subsequent LTE power ramps, the C/No baseline levels are achieved in the absence of LTE power. One can perhaps infer that Receiver 108 was not ready for the test start, that Receiver 108's Baseline C/No value is suspect or that the GPS simulator Carrier power rose after the start of logging. Any of these conditions would constitute an invalid test execution meriting a retest.

## Figure A.I.3

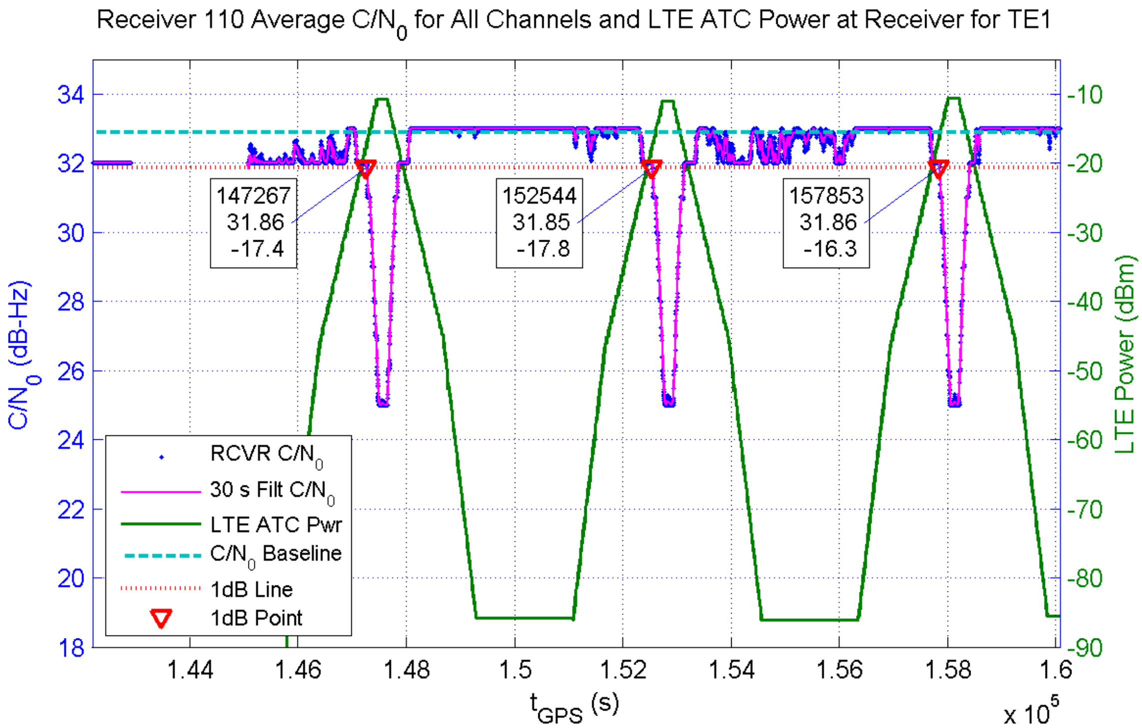


Receiver 108 Average C/N0 for All Channels and LTE ATC Power at Receiver for TE1
C/N0 (dB-Hz)
LTE Power (dBm)
tGPS (s)
x 10^5
53
52
51
50
49
48
47
46
45
-10
-20
-30
-40
-50
-60
-70
-80
-90
1.44
1.46
1.48
1.5
1.52
1.54
1.56
1.58
1.6
147326
50.05
-14.2
152579
50.05
-15.4
157896
50.05
-13.7
RCVR C/N0
30 s Filt C/N0
LTE ATC Pwr
C/N0 Baseline
1dB Line
1dB Point

### 2. Receiver 110 in TE1

In the review of Receiver 110, the plot anomalies are similar to those of Receiver 108, but not exactly the same. For Receiver 110, the initial C/No logging prior to the LTE power ramp displays almost a 1 dB degrading from the baseline as well as a data gap. It is not clear why this receiver's chart has a data gap.

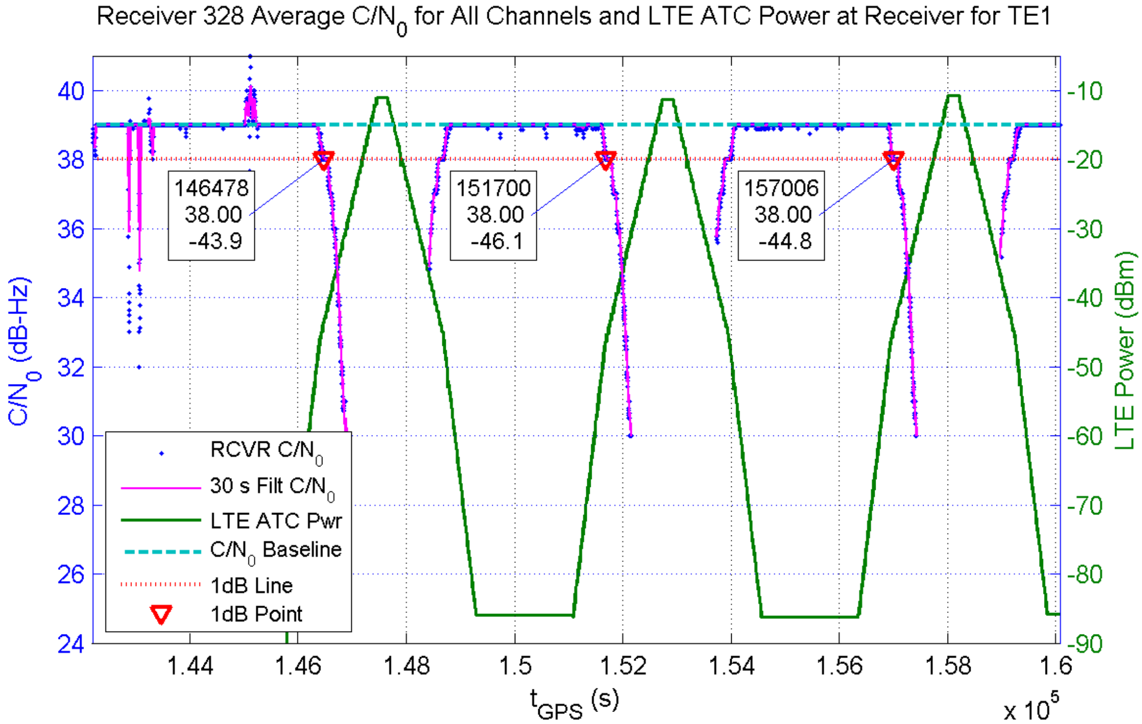
**Figure A.I.4**



### 3. Receiver 328 in TE1

The plot for this receiver shows considerable differences in detected 1dB C/No points between each of the three power ramps. To clearly establish C/No criteria, the device should have reported the C/No with less than 1dB variations between all three measurement samples.

**Figure A.I.5**



The same receiver was tested twice coded as 123 and 111 in TE1 and TE10. The plots for devices 123 and 111 show that although the results were quite consistent during the tests, there is close to 10 dB difference in reported C/No between TE1 and TE10. There is also a very large time variation in the quiescent $C/N_0$ (in the absence of the LTE signal) which is unexplained, especially given the high mean value of $C/N_0$.

**Figure A.I.6**

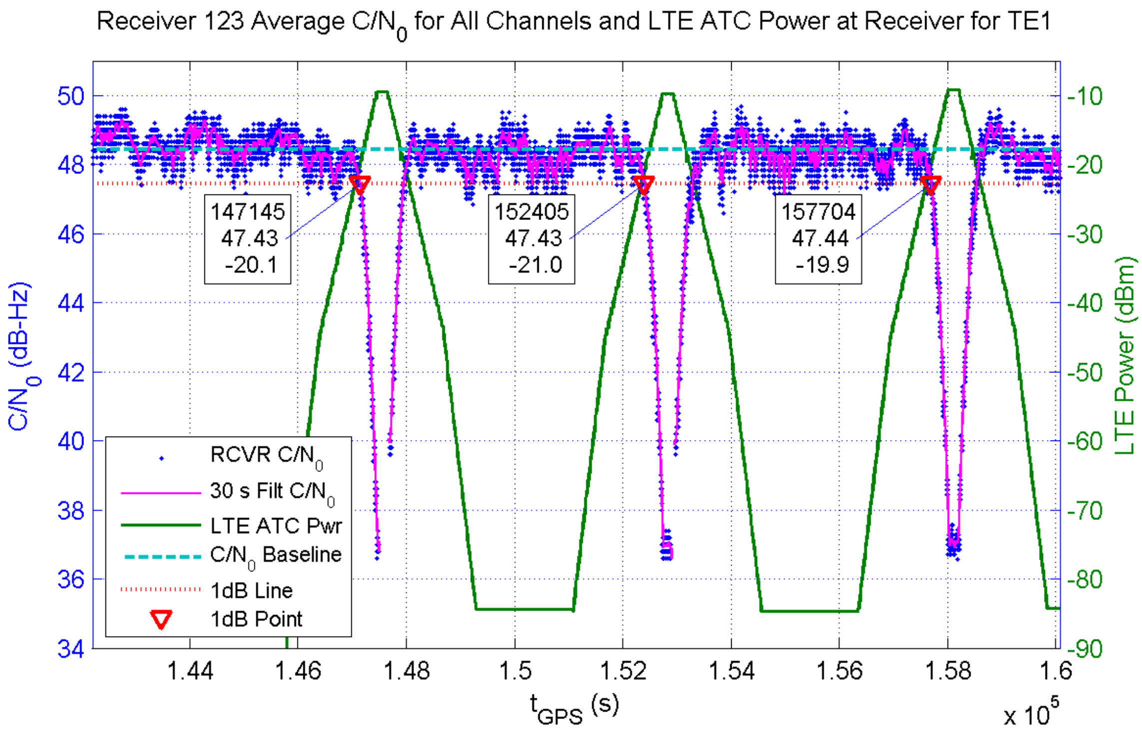
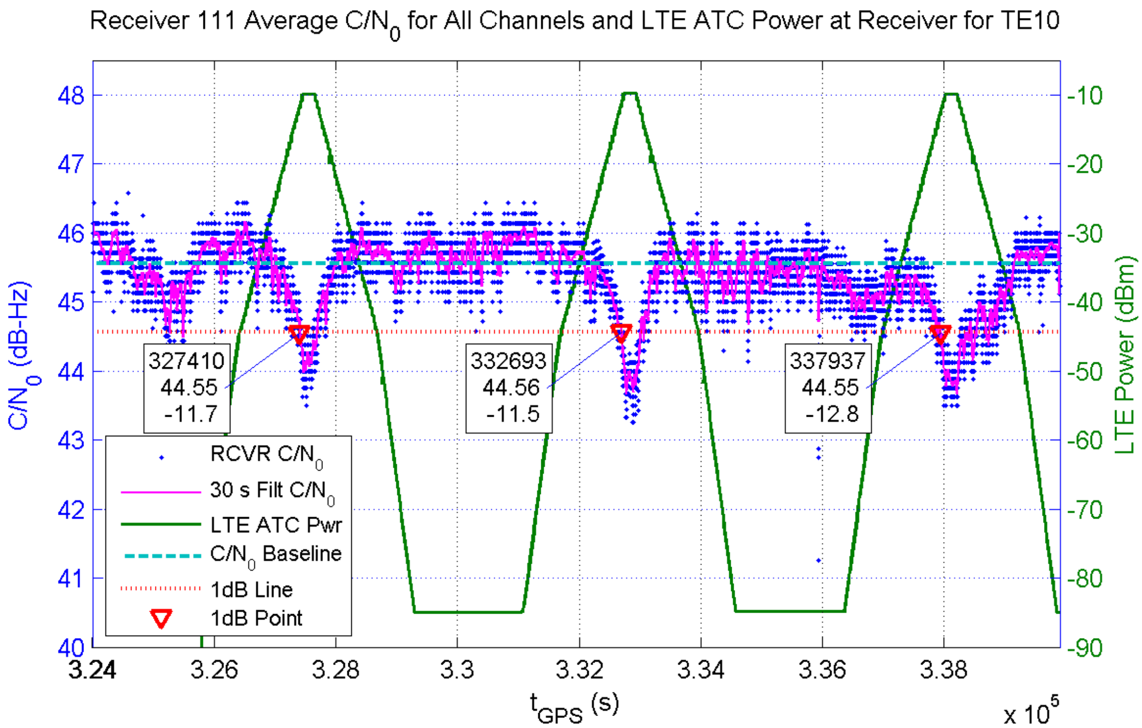


**Figure A.I.7**




Another revealing inconsistency is between the TWG tests and the NPEF tests. At least seven devices, belonging to three different GPS manufacturers, were subject to both TWG and NPEF tests.[18] Each of these seven devices generated data in the NPEF test that is inconsistent with TWG test results, as depicted below in Table A.I.1.

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[18] To maintain the anonymity of the manufacturers, LightSquared is using only the TWG and NPEF device numbers.

**Table A.I.1**

| | TWG Test | | | WSMR Test | | | Differential Results | |
|---|---|---|---|---|---|---|---|---|
| **Device Name** | **TWG Id** | **1dB de-sense** | **C/No** | **WSMR Id** | **1dB de-sense (dBm)** | **C/No (dB.Hz)** | **1dB de-sense diff (dB)** | **C/No diff (dB)** |
| Manufacturer A, 1 | G15343 | -32 | 42.8 | 211 | -29.5 | 38.08 | 2.5 | 4.72 |
| Manufacturer A, 2 | G10607 | 0 | 41 | 375 | -16.4 | 46.03 | 16.4 | 5.03 |
| Manufacturer B, 1 | G12867 | -13.3 | 47 | 113 | No results | No results | | |
| Manufacturer B, 2 | G17783 | 0 | 40 | 356 | -16.3 | 46.7 | 16.3 | 6.7 |
| Manufacturer B, 3 | P17655 | -2 | 42.2 | 124 | -16.1 | 44.06 | 14.1 | 1.86 |
| Manufacturer C, 1 | G16382 | -22 | 36 | 110 | -17.8 | 31.85 | 4.2 | 4.15 |
| Manufacturer C, 2 | G16382 | -22 | 36 | 313 | -33.5 | 34 | 11.5 | 2 |

Variation in the 1 dB de-sense testing between the two experiments ranged from a difference of 2.5 dB up to 16.4 dB. Variation in the quiescent $C/N_0$ testing ranged from a difference of 2 to 6.7 dB. These inconsistencies are neither mentioned nor explained in the analysis of the NPEF Report [1]. While differences in the test signals used or test methodology may account for some difference, the differences are substantial enough that they should have raised serious questions and resulted in additional testing to explore why the variations occurred.

In addition, test results for the devices of at least two GPS device manufacturers have confirmed that there were internal inconsistencies in NPEF's data. NPEF's test included eight GPS receivers made by the same manufacturer, as depicted in Table A.I.2 below.

**Table A.I.2**

| *Device Name* | *WSMR ID* | *1dB de-sense (dBm)* | *C/No(dB.Hz)* |
|---|---|---|---|
| **Category 1 Devices** | | | |
| Manufacturer X Device A | 105 | -23 | 41.38 |
| Manufacturer X Device B | 383 | -15.9 | 36.93 |
| **Category 2 Devices** | | | |
| Manufacturer X Device C | 395 | No results | 25 |
| Manufacturer X Device D | 307 | -18 | 34.96 |
| Manufacturer X Device E | 327 | -15.4 | 37.01 |
| Manufacturer X Device F | 333 | -27 | 44.99 |
| Manufacturer X Device G | 360 | -26.7 | 45 |
| Manufacturer X Device H | 373 | -30.1 | 45 |

Two of the receivers, Device A and Device B, were identical in all features except software, yet experienced degradation levels that differed by 7.1 dB. They also showed quiescent $C/N_0$ values that differed by a factor of roughly 4.5 dB. The manufacturer's other six receivers also had identical features, except for their software. Yet, for these devices the 1dB de-sense results ranged from -15.4 to -30.1 dB[19] and no two results were identical. The same is true of the quiescent $C/N_0$ value, which ranged from 25-45 dB.Hz. The NPEF Report [1] makes no mention of these inconsistencies in substantially identical devices.

### D. Key data was not reported

While the report states that "[e]ach receiver's $C/N_0$ was collected",[20] if this is true then NPEF only reported a subset of the information that it received from the participants. The report contains no results for Test Events 2 & 11, which may have shown compatibility. Without the full data set it is impossible to cross check the findings against other performance indicators or even check for consistency of the data to the reported results.

Moreover unlike the TWG tests, in the NPEF tests, LightSquared was not provided access to the "raw data" produced by the receivers. These were collected by the manufacturers, processed in ways unknown to LightSquared and perhaps even to NPEF. What was provided to NPEF was then processed further processed and passed to LightSquared as plots of $C/N_0$ versus adjacent band signal power. In other words, in the present case, the results were presented to LightSquared on an *as is* basis. Thus, LightSquared was unable to perform the same assessment of the data as it did for the TWG tests, which assessment had revealed many anomalies. (Even then, there are several glaring anomalies and inconsistencies in the data, as described in Section C, above.)

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[19] For one of the six Category 2 devices there were no 1dB de-sense results. These figures, therefore, only reflect results for the other five devices.

[20] NPEF Report [1], at p. 13.

In addition, it is unclear why there are missing results for so many devices in so many tests. Based on a review of Appendix D of the report, results are reported for all tests for only \ eight Personal/General Navigation devices. This low percentage suggests either that the tests were done in a hurry without appropriate quality control or that there were additional problems which were not reported.

The following table shows the test completions for the devices. The test design called for each test to be repeated twice. The schedule had each test performed once, these were labeled test events 0-8, and then performed again, producing test events 9-17. By this design each device would have been tested twice, allowing for confirmation of test results and providing some insight on test-to-test repeatability. Additionally, within each individual test the device saw the same power levels during the ramp up and ramp down cycles. So the original test design would present the same power level to a device twice in each test and tested each device twice for a total of four exposures to each power level. Having this kind of test repeatability is extremely important in gauging the stability and repeatability of test results.

In the table below Suite 1 is the first cycle of tests and Suite 2 is the second cycle of tests.

**Table A.I.3**

| | General Location & Navigation | | Other | |
|---|---|---|---|---|
| | Devices | Percentage | Devices | Percentage |
| Test Suites Completed | | | | |
| Suite 1 only | 32 | 31.4% | 12 | 28.6% |
| Suite 2 only | 27 | 26.5% | 5 | 11.9% |
| Both Suites | 8 | 7.8% | 1 | 2.4% |
| Suite 1 but not 2 | 2 | 2.0% | 3 | 7.1% |
| Suite 2 but not 1 | 5 | 4.9% | 2 | 4.8% |
| Neither | 28 | 27.5% | 19 | 45.2% |
| Total | 102 | 100.0% | 42 | 100.0% |

It is alarming that only 7.8% of the devices were able to complete both test suites and this fact alone raises very serious questions. The basic design of the test was undermined by this low completion percentage. Additional questions arise when contemplating why so few devices were sufficiently stable so as to be able to successfully complete both test suites.

IEEE 1900.2 [13] also provides strong guidance that coexistence analysis should quantify the variability that influences the analysis. The important factors identified to this point, and others to be discussed later, must be taken into account in any reasoned analysis. Subclause 9.7 of IEEE 1900.2 [13] states:

### 9.7 Analysis uncertainty

All analyses and measurements have an associated uncertainty. This sub-section requires the analyst to explicitly state the uncertainty of their findings.

### 9.7.1 Uncertainty distribution

When developing an analysis emphasis may be given to minimizing the possibility of a false positive finding, a false negative finding or balancing the two. The analysis should state the emphasis used and the rational for it. There are legitimate reasons why an analysis will choose one emphasis or the other. The effect will be, where there is uncertainty, to deal with it to achieve the desired goal. If one analysis intends to assure with 95% confidence that interference will not be underestimated while a second seeks to assure with the same confidence that inference will not be overestimated then the results may be quite different. By stating the intent of the analysis the reason for divergent results can be more readily identified.

This directive is also found in ISO 17025 [12], subclause 4.13.2.1, which directs:

The records for each test or calibration shall contain sufficient information to facilitate, if possible, identification of factors affecting the uncertainty and to enable the test or calibration to be repeated under conditions as close as possible to the original.

Test repeatability and measurement uncertainty are not reported as is required by ISO 17025 [12]. NPEF's does not report measurement uncertainty nor is test repeatability evaluated. As stated above, proper coexistence analysis needs to include a probability distribution due to the relevant variables involved. Equally the testing should have evaluated and quantified its measurement uncertainty. ISO 4.13.2.1 applies here as well and further direction on calculating and reporting uncertainty with test data is given in ISO 17025 [12], subclause 5.4.5.3:

5.4.5.3 The range and accuracy of the values obtainable from validated methods (e.g. the uncertainty of the results, detection limit, selectivity of the method, linearity, limit of repeatability and/or reproducibility, robustness against external influences and/or cross-sensitivity against interference from the matrix of the sample/test object), as assessed for the intended use, shall be relevant….

ISO 17025 [12] subclause 5.4.6 provides further guidance:

**5.4.6 Estimation of uncertainty of measurement**

…..

**5.4.6.2** Testing laboratories shall have and shall apply procedures for estimating uncertainty of measurement. In certain cases the nature of the test method may preclude rigorous, metrologically and statistically valid, calculation of uncertainty of measurement. In these cases the laboratory shall at least attempt to identify all the components of uncertainty and make a reasonable estimation, and shall ensure that the form of reporting of the result does not give a wrong impression of the uncertainty.

The testing was conducted with a 30 minute baseline, followed by a 15 second dwell time at each power level, increasing to 30 seconds at the higher power levels and a 3 minute dwell time at the maximum power level. During these intervals each device would have performed many measurements. However, no information is presented on how those many measurements were analyzed and used. Was the worst-case reading reported, an average of the readings or some other method used? Further the variation in readings for each time interval is necessary to know in order to understand the stability of the test. Both the method for selecting a value for use in the analysis and the range of readings at each step should be reported and is clearly called for by standard testing practices as shown by ISO 17025 [12].

### E. Environmental noise was not properly taken into account

NPEF assumed in its tests that the background noise floor is exclusively due to the receiver's internal thermal noise. This assumption is flawed because the RNSS band is subject to received co-channel noise from many sources, including harmonics of terrestrial transmitters far outside the GPS band, other navigation satellites and sky noise. Aviation standards account for this by allowing a margin for "environmental noise", as described below.[21]

The RTCA MOPS recommend that broadband noise should be added to the receiver in any test set-up designed to assess interference to aviation receivers.[22] The NPEF tests/analyses did not follow this protocol. It is noteworthy that, in the RTCA/TWG testing of aviation receivers, this environmental noise was properly taken into account.[23] It is not possible to theoretically predict, in a general way, the effect of increased background noise on the 1 dB $C/N_0$ degradation threshold of randomly selected receivers. The effect will depend on the receiver implementation, i.e. the actual mechanism causing $C/N_0$ degradation in the particular receiver owing to strong adjacent band signals. For instance, if the effect is to cause receiver gain compression, the de-sense threshold may not be affected; if the effect is to cause a rise in the internal noise floor of the receiver, such as through reciprocal mixing or A/D aliasing, the de-sense threshold could be higher to the extent calculated below.

The rise of the composite noise floor, for a fixed amount of received environmental noise, depends on the noise figure of the receiver. The rise is 3 dB for a receiver with 2 dB noise figure, 2.6 dB for 3 dB noise figure, and 2.2 dB for 4 dB noise figure receiver. The calculation for 3 dB receiver noise figure is shown below.

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[21] RTCA/DO-229D, Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment, Section C.2.3 (December 13, 2006) ("RTCA/DO-229D [14]"); RTCA/DO-235B, Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band, Section 15-4, ¶ 6 (March 13, 2008) ("RTCA/DO-235B [15]").

[22] RTCA/DO-229D [14], at Section M.5.1.

[23] RTCA/DO-327, Assessment of the LightSquared Ancillary Terrestrial Component Radio Frequency Interference Impact on GNSS L1 Band Airborne Receiver Operations, Section D.1.1 (June 3, 2011) ("RTCA/DO-327 [16]").

**Table A.I.4**

| | | |
|---|---|---|
| Typical Rx NF | 3 | dB |
| Thermal PSD (No') | -171.0 | dBm/Hz |
| Effective Noise Density of for all GNSS sources (Io) | -171.9[24] | dBm/Hz |
| Corrected No = Io + No' | -168.4 | dBm/Hz |
| Correction in Carrier power for the same degradation | 2.6 | dB |

If, for example, nonlinear effects are causing the internal noise floor of the receiver to rise, then, in order to cause 1 dB degradation in the observable noise floor, the latter has to rise 2.6 dB more in the case where there is external noise relative to the case where there is no external noise. If it is further assumed that the rise in internal noise floor is linearly proportional with respect to the adjacent channel signal power (itself a conservative assumption as shown by many instances in the NPEF test results), then the desense threshold will be 2.6 dB higher.

## II. THERE IS NO SCIENTIFIC SUPPORT FOR NTIA'S REFUSAL TO ANALYZE COMPATIBILITY BASED ON LIGHTSQUARED'S POWER ON THE GROUND PROPOSAL

In October 2011, in an effort to move the discussion past what proved to be a contentious topic of the choice of propagation models, LightSquared proposed to limit its power on the ground to -30 dBm initially and -27 dBm after several years.[25] The proposal contains two options. One option involves a reduction in base station power for transmitters closer to the ground and a modified version of the Walfisch Ikegami Line of Sight (WILOS) model (the "Height-Power Option"). The other option involves an intensive program of post-deployment measurement to identify and correct any "hot spots" (the Measurement-Based Option"). With either option, LightSquared stated a willingness to further adjust its network if third-party measurements indicated that hot spots remained. LightSquared informally also expressed a willingness to limit its base station deployment to Left Hand Circularly Polarized (LHCP) antennas, which would have the effect of further reducing its power on the ground from the perspective of a GPS receiver.

[24] RTCA/DO-327 [16], at Section 3.1.1.

[25] LightSquared, Ex Parte Notification, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (October 6, 2011) ("LightSquared Ex Parte Letter [3]"); *see also* Letter from Jeffrey Carlisle, Executive Vice President Regulatory Affairs and Public Policy, LightSquared, Inc. to Julius Knapp, Chief, Office of Engineering and Technology, FCC, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (December 7, 2011) ("LightSquared Update [20]") (providing further detail to the FCC about LightSquared's power on the ground proposal"); Letter from Jeffrey Carlisle, Executive Vice President Regulatory Affairs and Public Policy, LightSquared, Inc. to Marlene H. Dortch, Secretary, FCC, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (December 12, 2011) ("LightSquared Update [21]") (updating LightSquared's power on the ground proposal by (1) eliminating the final power increase phase (establishing a maximum power of -27 dBm after January 1, 2016) and (2) extending the period during which it will maintain the power at -30 dBm to January 1, 2016).

The NTIA Letter [4][26] ignores LightSquared's highly constructive proposals without explanation. Instead, it insists on analyzing the NPEF tests based on an assumed -15 dBm power on the ground from LightSquared operations, and apparently based on using a propagation model that assumes nearly free-space, which is demonstrably too conservative. As discussed below, NTIA's assumptions vastly overstate the actual power to which a GPS device will typically be exposed. Either of LightSquared's options and its LHCP proposal would have provided a far more reasonable approach to ensuring compatibility for the practically all personal/general navigation devices operating almost anywhere near a LightSquared base station.

### A. NTIA's choice of base station power and propagation models was inappropriate

A fundamental error in NTIA's analysis is its failure to consider the power at which LightSquared is proposing to operate its base stations, particularly those at lower heights. The following table provides LightSquared's proposed EIRP reduction schedule.[27]

[26] Letter from Lawrence E. Strickling, NTIA, to Julius Genachowski, Chairman, FCC (February 14, 2012) ("NTIA Letter [4]").

[27] Following submission of the LightSquared Ex Parte Letter [3], LightSquared further modified its proposal to limit power on the ground. The updated proposal is reflected in Table A.II.1 and were provided to NTIA prior to submission of the NTIA Letter [4].

**Table A.II.1 LightSquared's Proposed Base Station EIRPs for Modified WILOS and Threshold of -30 dBm (free space propagation up to 100 m and WILOS thereafter)**

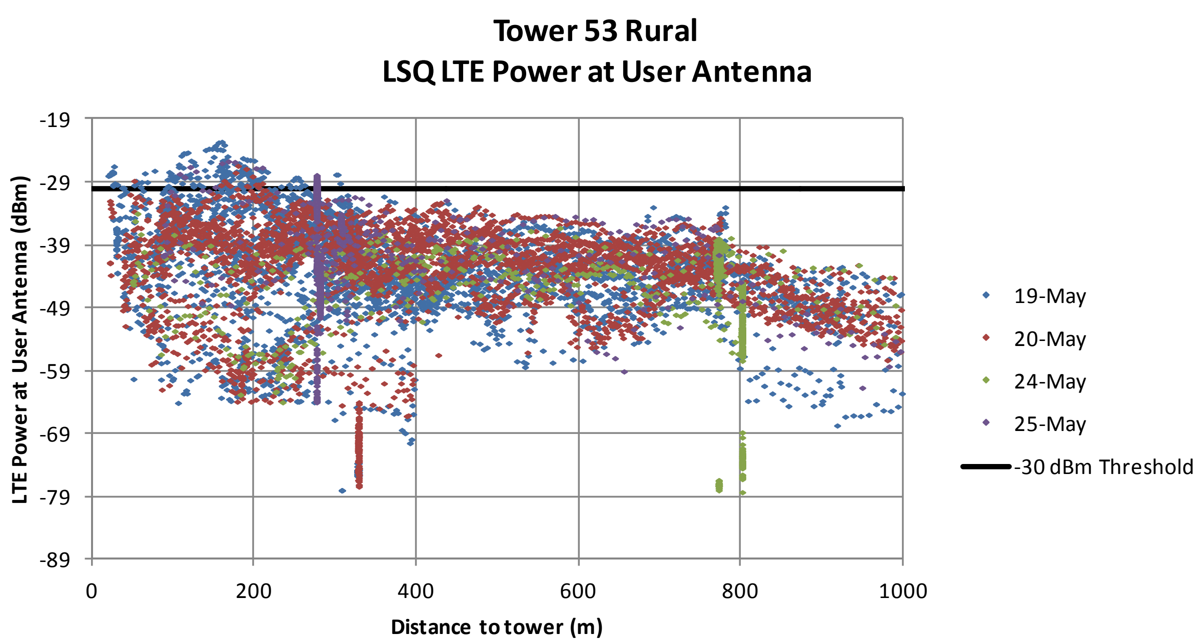
| BS Antenna Height (m) | Power Reduction (dB) | Maximum Allowed EIRP (dBm) Argus Antenna |
|---|---|---|
| 4 | 26 | 36 |
| 5 | 23.1 | 39 |
| 6 | 20.9 | 41 |
| 7 | 19.2 | 43 |
| 8 | 17.7 | 44 |
| 9 | 16.5 | 46 |
| 10 | 15.4 | 47 |
| 11 | 14.4 | 48 |
| 12 | 13.6 | 48 |
| 13 | 12.8 | 49 |
| 14 | 11.9 | 50 |
| 15 | 11 | 51 |
| 16 | 10.2 | 52 |
| 17 | 9.5 | 53 |
| 18 | 8.8 | 53 |
| 19 | 8.1 | 54 |
| 20 | 7.5 | 55 |
| 21 | 6.9 | 55 |
| 22 | 6.3 | 56 |
| 23 | 5.8 | 56 |
| 24 | 5.3 | 57 |
| 25 | 4.8 | 57 |
| 26 | 4.3 | 58 |
| 27 | 3.9 | 58 |
| 28 | 3.4 | 59 |
| 29 | 3 | 59 |
| 30 | 2.6 | 59 |
| 31 | 2.2 | 60 |
| 32 | 1.8 | 60 |
| 33 | 1.5 | 61 |
| 34 | 1.1 | 61 |
| 35 | 0.8 | 61 |
| 36 | 0.5 | 62 |
| 37 | 0.1 | 62 |
| >38 | 0 | 62 |

Instead of using these power levels for its analysis, however, NTIA appears to have assumed that all LightSquared base stations would operate at the maximum power of 32 dBW EIRP, regardless of height. It then used this assumption and measurements taken in field tests in the Las Vegas area in May 2011 from three test sites to settle on a propagation model that essentially assumes free-space propagation for more than a mile from each base station.[28] NTIA appears to have rejected the use of WILOS because it would have under-predicted the power on the ground.

NTIA's assumption is fundamentally flawed as the Las Vegas field data can actually be useful in demonstrating the utility of cell site power reductions based on use of the Modified WILOS model. To demonstrate this point, LightSquared has performed an analysis of the Las Vegas field data, adjusted to reflect the power reductions that would be implemented as a result of its proposed Height-Power Option. For the three test sites, LightSquared has reduced the actual EIRP by the values dictated by Table A.II.1 above. Utilizing these reduced values, and adjusting these field measurements on a dB-for-dB basis, it is clear that the actual power on the ground is limited to -30 dBm or less at almost all locations. The dB-for-dB reduction in received power is appropriate as the propagation medium is completely linear.

Figure A.II.1 below shows the Las Vegas data from rural site #53.[29] This site had the highest levels of power on the ground and used an 18 m high antenna.

**Figure A.II.1 Las Vegas data for Rural Site #53 collected by Trimble, adjusted for base station EIRP reduction of 9 dB corresponding to antenna height of 18 m.**




[28] NPEF Report [1], at 22-25.

[29] Working Group, Final Report, IB Docket No. 11-109, Figure.32: Trimble Reported Field Data for Test Site 53 (June 30, 2011) ("TWG Final Report [17]").

The distribution analysis for this data is shown in Table A.II.2 below.

**Table A.II.2 CDF for Trimble Reported Data Set for Site #53**
**TWG Final Report, Figure 3.2.34**

| **Power (dBm)** | **Frequency** | **CDF %** |
|---:|---:|---:|
| -60 | 1539 | 13.25% |
| -55 | 650 | 18.84% |
| -50 | 881 | 26.42% |
| -45 | 1657 | 40.69% |
| -40 | 3085 | 67.24% |
| -35 | 2259 | 86.68% |
| -30 | 1235 | 97.31% |
| -25 | 296 | 99.86% |
| -20 | 16 | 100.00% |

Table A.II.2 shows that for an 18 m high antenna, as used in site #53, the LightSquared proposed improvements to NTIA's Height-Power Model would have resulted in a probability of approximately 97% for the power being less than or equal to -30 dBm, or 3% probability for the threshold level ever being exceeded.

The same analysis was performed for the suburban site #68, where the antenna height was 17 m, and the urban site #160, where the antenna height was 15.2 m. The results for all three locations are summarized in Table A.II.5.

**Figure A.II.2 Las Vegas data for Suburban Site #68 collected by Trimble, adjusted for base station EIRP reduction of 9 dB corresponding to antenna height of 17 m**

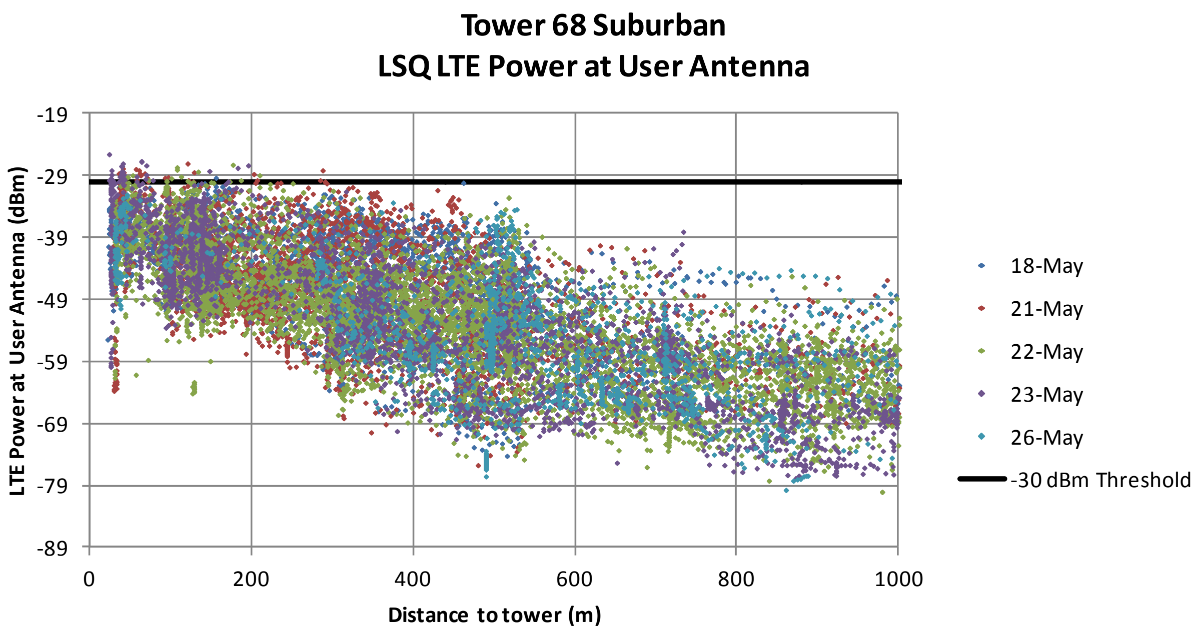



**Table A.II.3 CDF for Trimble Reported Data Set for Site #68 TWG Final Report, Figure 3.2.26**

| Power (dBm) | Frequency | CDF % |
|---|---|---|
| -60 | 3884 | 18.22% |
| -55 | 3202 | 33.25% |
| -50 | 2773 | 46.26% |
| -45 | 3491 | 62.64% |
| -40 | 4329 | 82.95% |
| -35 | 2660 | 95.43% |
| -30 | 877 | 99.55% |
| -25 | 96 | 100.00% |
| -20 | 0 | 100.00% |

**Figure A.II.3 Las Vegas data for Urban Site #160 collected by Trimble (TWG Final Report, Figure 42) adjusted for base station EIRP reduction of 11 dB corresponding to antenna height of 15.2 m**

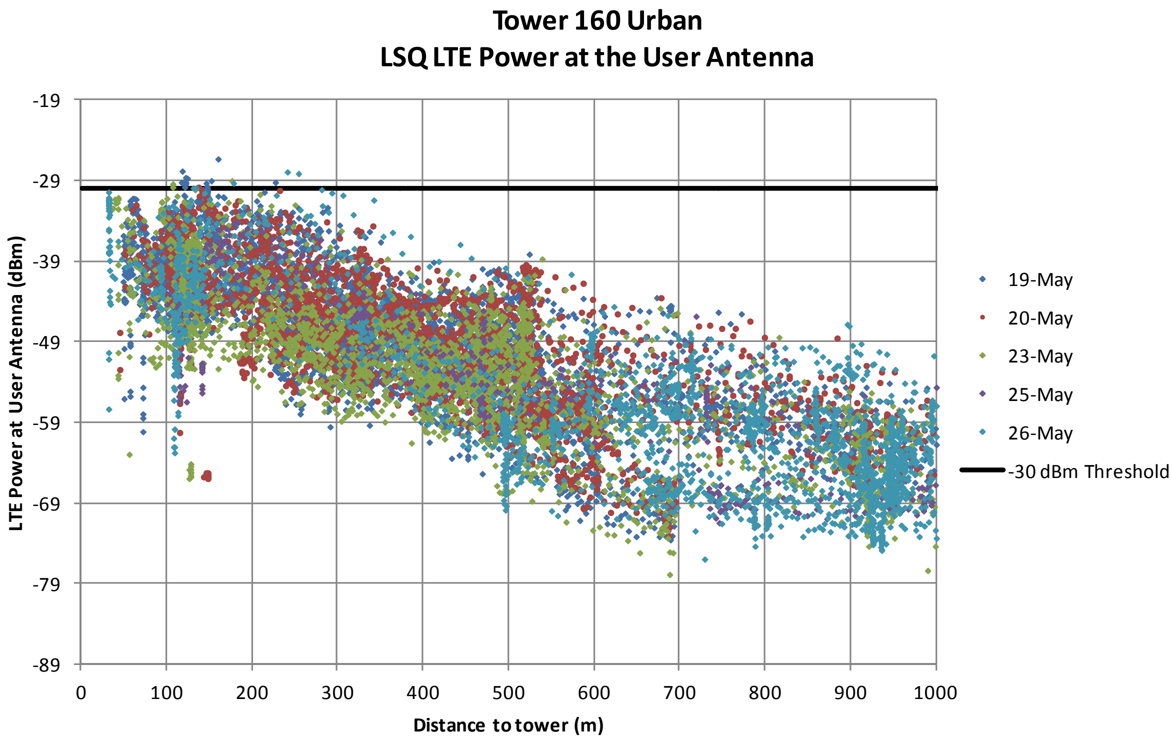



**Table A.II.4 CDF for Trimble Reported Data Set for Site #160**

| Power (dBm) | Frequency | CDF % |
|---|---|---|
| -60 | 3841 | 32.86% |
| -55 | 2313 | 52.64% |
| -50 | 1791 | 67.96% |
| -45 | 1692 | 82.44% |
| -40 | 1010 | 91.08% |
| -35 | 726 | 97.29% |
| -30 | 291 | 99.78% |
| -25 | 26 | 100.00% |
| -20 | 0 | 100.00% |

**Table A.II.5 Summary Results Showing Applicability of LightSquared Proposed Modified WILOS Model to Las Vegas Field Data**

| | Rural Site #53 | Suburban Site #68 | Urban Site #160 |
|---|---|---|---|
| Antenna Height (m) | 18 | 17 | 15.2 |
| EIRP Backoff as per LightSquared Proposal (dB) | 9 | 9 | 11 |
| Measured probability of power on the ground exceeding -30 dBm | 2.7% | 0.4% | 0.2% |

Table A.II.5 shows that, had the Height-Power approach (free space up to 100 m and WILOS thereafter) proposed by LightSquared been used to adjust the base station powers in Las Vegas, the *actual* probability of exceeding the objective threshold of -30 dBm would have been very small (2.7% to 0.2% in the above examples). Moreover, the morphology around site #53 (2.7% probability) – a site in the Nevada desert at one end of a huge crater and with relatively smooth ground, in the absence of any blockage or ground clutter for over 10 km – is atypical of most morphologies where LightSquared's network will be deployed. Hence the 2.7% value noted above for site #53 may be taken as an upper limit of the probabilities likely to be encountered in typical environments. The value of approximately 0.5% is expected to be more typical across all morphologies.

This also demonstrates how the Irregular Terrain propagation model ("ITM") that NTIA used is completely inappropriate for this task. According to NTIA's own manual, the model is intended for use at distances greater than 1 km.[30] An analysis using the extremely conservative free space propagation model shows that LightSquared's highest power levels on the ground will be achieved at distances ranging from 100-400 meters from the base of the transmit antenna tower (depending on antenna height) – which are clearly not within the area for which ITM is intended. Figures A.II.4 and A.II.5 below demonstrate the maximum expected power on the ground for antennas of 15 meters and 50 meters in height, using LightSquared's base station antenna patterns and the overly conservative free space propagation model.[31]

[30] NPEF Report [1], at F-3 FN1 (citing National Telecommunications and Information Administration Institute for Telecommunications Sciences, NTIA Report 82-100, A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode (April 1982)); *see also* Table A.II.1.

[31] A free space propagation model is appropriate for this limited exercise of predicting the *points* of highest power, since it is a relative measurement (e.g.: identification of the physical location of highest power, without regard to the power level that is actually estimated).

**Figure A.II.4 - Power on the ground as a function of distance for a 15 m high base station antenna**

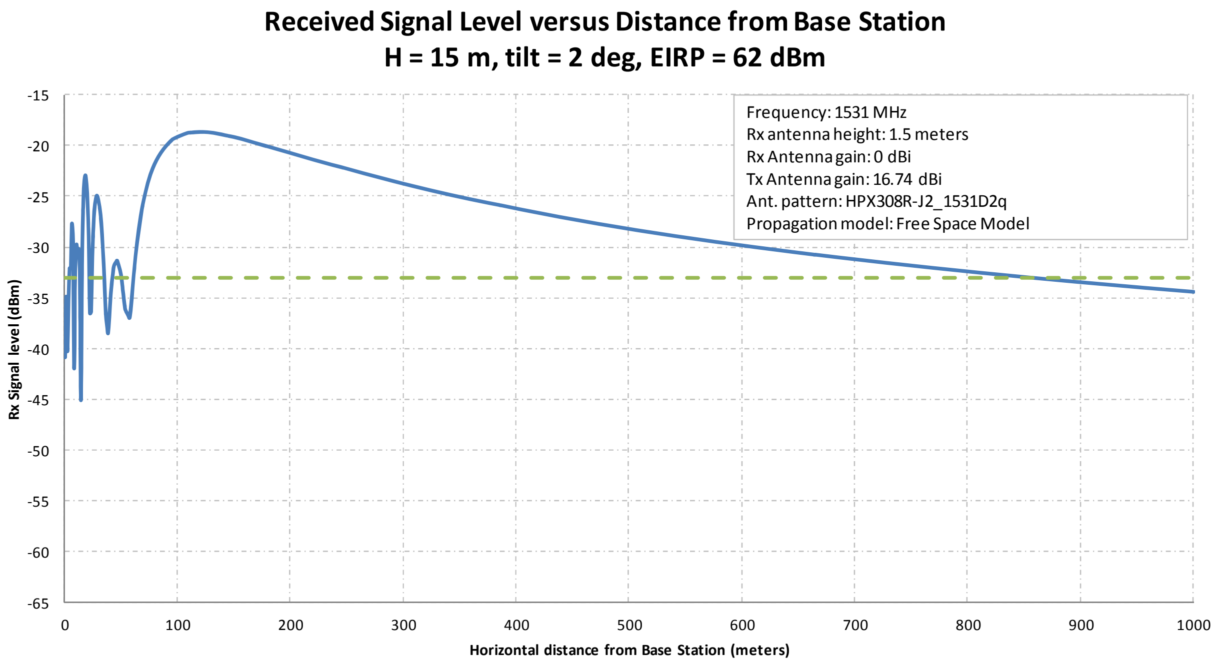
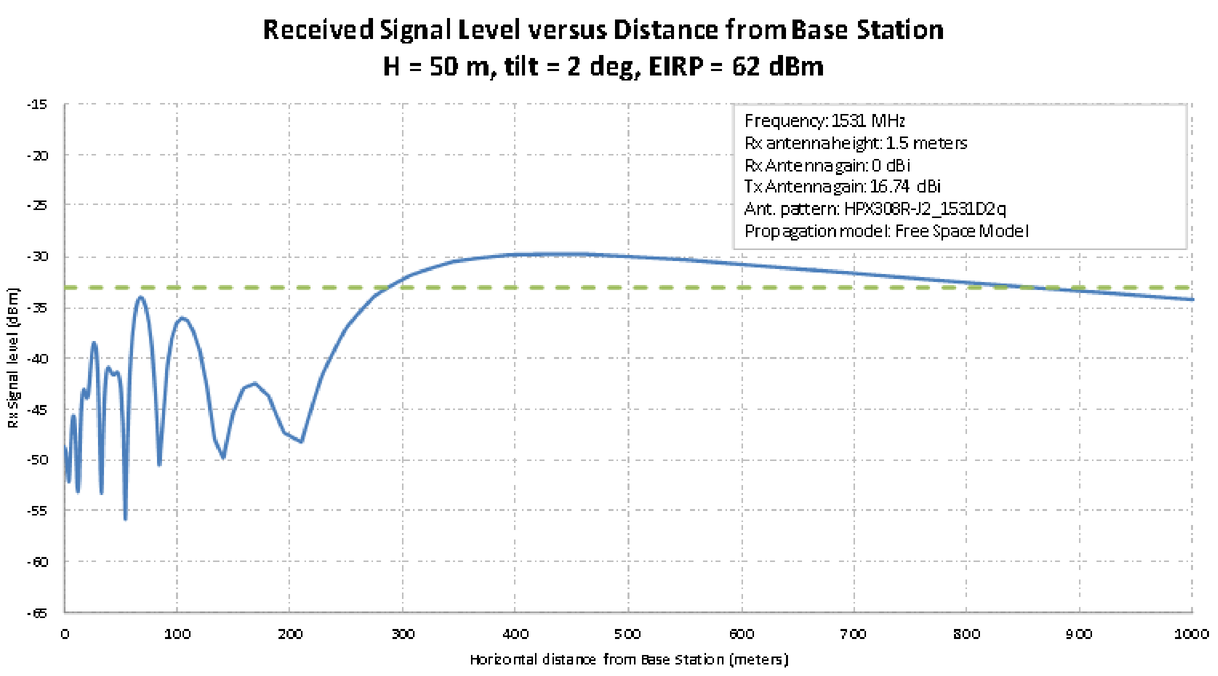
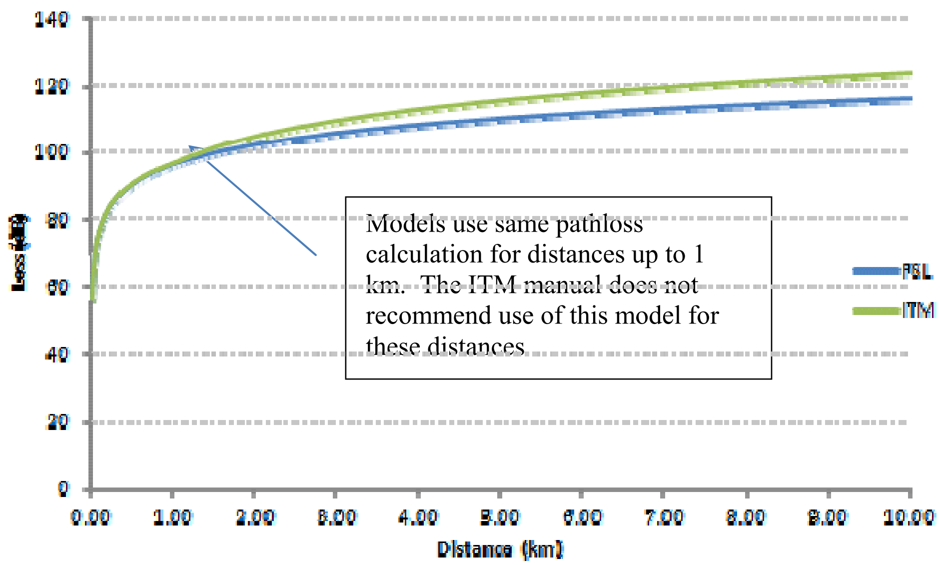


**Figure A.II.5 - Power on the ground as a function of distance for a 50 m high base station antenna**




In reality, the ITM model uses a free space line of sight calculation for distances of 1 km or less. Because LightSquared's maximum power will be achieved within this 1 km zone, there is no practical difference between a free space model and the ITM for NTIA's intended use.

**Figure A.II.6 - Variation of power on the ground with distance for ITM and FSL**



Furthermore, the Longley-Rice model, which is the basis of the ITM, has been criticized as being unsuitable for modeling urban clutter.[32] According to Rappaport [5],

> One shortcoming of the Longley-Rice model is that it does not provide a way of determining corrections due to environmental factors in the immediate vicinity of the mobile receiver, or consider correction factors to account for the effects of buildings and foliage. Further, multipath is not considered.

In Parsons [6][33] the author states,

> Since the original publication there have been several revisions and modifications of the Longley-Rice model and some corrections have been made. … One significant development, relevant to mobile radio propagation, has been the introduction of an urban factor (UF) used to make predictions in urban areas….

The ITM model does not use this correction factor and consequently dramatically overestimates the RF power levels. Is this the difference between fast fading and slow fading and its impact on devices?]Using the urban factor correction leads to an increase of the median path loss at 1 km by 34 dB.[34] In summary, the classic ITM model is an older model that has been revised substantially and superseded by newer models, none of which are considered by the NTIA.

It may be further noted that unlike the NTIA, the FAA used a cellular clutter model (modified Hata-Okumura) for path geometries that would have a high likelihood of encountering urban clutter. For an aircraft parked at a runway, the modified Hata-Okumura model would be used if a clear line of sight did not exist with respect to a given base station.[35] In the same scenario, the NTIA would use free space propagation if the distance was less than 1 km, *regardless of blockages*. It is noteworthy that whereas the FAA's model is *site-specific*, i.e. acknowledges the presence of blockages, the NTIA's ITM model does not.

The extent to which NTIA's insistence on the ITM model is unreasonable, relative to the use of actual terrain and obstacle data, is easily illustrated by showing the levels of power on the ground in the Washington, D.C. area using an industry-standard RF planning tool (CelPlan©). This tool was run assuming free space propagation, both with and without terrain and morphology[36] (collectively, "obstacles").

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32 Rappaport, T. D., Wireless Communications and Practice (2 Ed.), Prentice Hall, 2002. pp. 145-46 ("Rappaport [5]").

33 Parsons, J. D. The Mobile Radio Propagation Channel (2. Ed.), John Wiley and Sons, Chichester, UK, 2000 p. 60 (Parsons [6]).

34 According to Parsons, UF (dB) = $16.5 + 15*\log_{10}(f/100) - 0.12\,d$, where f is in MHz and d is in kilometers. For f = 1531 MHz and d = 1 Km, UF = 34.1 dB.

35 *See* Technical Appx. Exhibit B, *infra*.

36 The analysis utilizes 1 meter resolution obstruction data for the densest portions of downtown Washington, DC. This is commercial data based on detailed surveys of actual buildings and obstructions in order to provide a highly accurate representation of the impact of actual building clutter on signal propagation. Areas outside of the downtown area utilize 30 meter resolution data.

Figure A.II.7 shows the input parameters. The base stations were assumed to operate at full power (32 dBW) regardless of antenna height, except where they were bound to a lower limit by LightSquared's existing requirement to operate at lower power near airports and navigable waterways.

Figure A.II.8 shows the coverage area. The tool was used in two modes: (i) free space propagation everywhere*, ignoring* obstacles, shown in Figure A.II.9 (the approach used by ITM) and (ii) free space propagation *considering* obstacles, shown in Figure A.II.10.

Figures A.II.9 and A.II.10 show that, if obstacles are ignored, the estimated power level would exceed -30 dBm over large areas (55%), which would require significant, but unnecessary, reductions in base station EIRP to achieve a -30 dBm threshold. To compensate for the impact of this on network coverage, there would have to be a significant increase in the number of base stations and a corresponding increase in network cost. In contrast, the red areas comprise 2-3%[37] of the coverage area when terrain and blockages are considered. This demonstrates the massive inefficiency which is created by NTIA's insistence on use of an overly conservative propagation model, that its own documentation acknowledges is not well suited for this type of task. LightSquared's Measurement-Based approach provides the needed RF environment to assure continued performance of general location/navigation devices, without inserting unnecessary (and expensive) excess margin.

In addition to the use of an incorrect propagation model, NTIA has further demanded that the power on the ground be limited to -33 dBm, without providing reasonable justification for such a requirement. This change compounds the exceedingly large, and unnecessary, economic burden on LightSquared as compliance would necessitate the construction of a large number of additional cell sites in order to provide appropriate levels of terrestrial coverage.

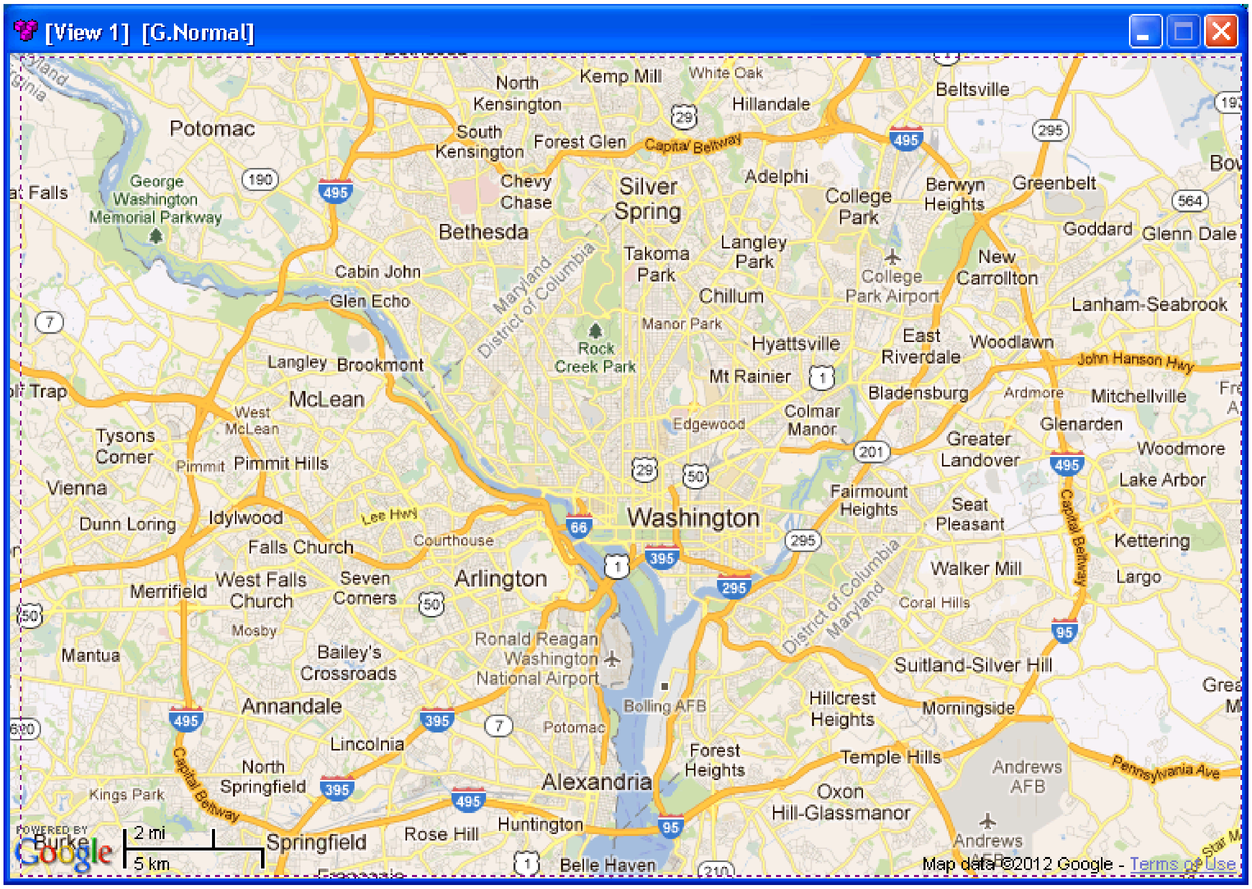
These coverage maps show the combined impact of reducing the pass/fail criterion from -30 dBm to -33 dBm, when using an extremely lossless propagation model such as ITM, as shown in Figure A.II.9, compared to a real world deployment scenario, shown in Figure A.II.10. In the former case, when terrain/obstacles are ignored, the affected area increases from 55% to 88%. In the latter case, when terrain/obstacles are considered, the affected area increases from 2% to 3%.

[37] In the results shown in Figure A.II.10, blockages were modeled as infinite attenuation. Results were also produced using the diffraction option of the tool and a high resolution terrain/obstacle database to make the loss finite and more realistic. However, the impact on the coverage map was small; the affected area for -30 dBm threshold went up by 1%. This difference is irrelevant to the point being made here, which is the huge difference with respect to the coverage map shown in Figure A.II.9, where terrain and obstacles are ignored.

**Figure A.II.7 - Prediction parameters**

| Parameters | Inputs |
|---|---|
| Area | 1,300 $km^2$ area centered on the District of Columbia |
| Tower database | LightSquared tower data ("Tower Data") |
| Antenna pattern | Argus (1531MHz) (Electronically Down Tilt to 2 degrees) |
| Antenna height and azimuth | Tower Data |
| Antenna azimuth | Tower Data |
| Mechanical tilt | Fixed in 0º |
| EIRP | Tower Data |
| Path Loss Model | Free Space model |
| GIS data | Scenario 1: No GIS database used<br>Scenario 2: 1-meter building layer, 30-meter clutter and terrain databases |
| Prediction resolution | 3 sec = 90 meters |
| Receiver height | 1.6 meters |

## Figure A.II.8 - Study area




## Figure A.II.9 - Aggregated received signal level prediction (using Free Space Line of Site without clutter)

(Sum of the received signals in each pixel)

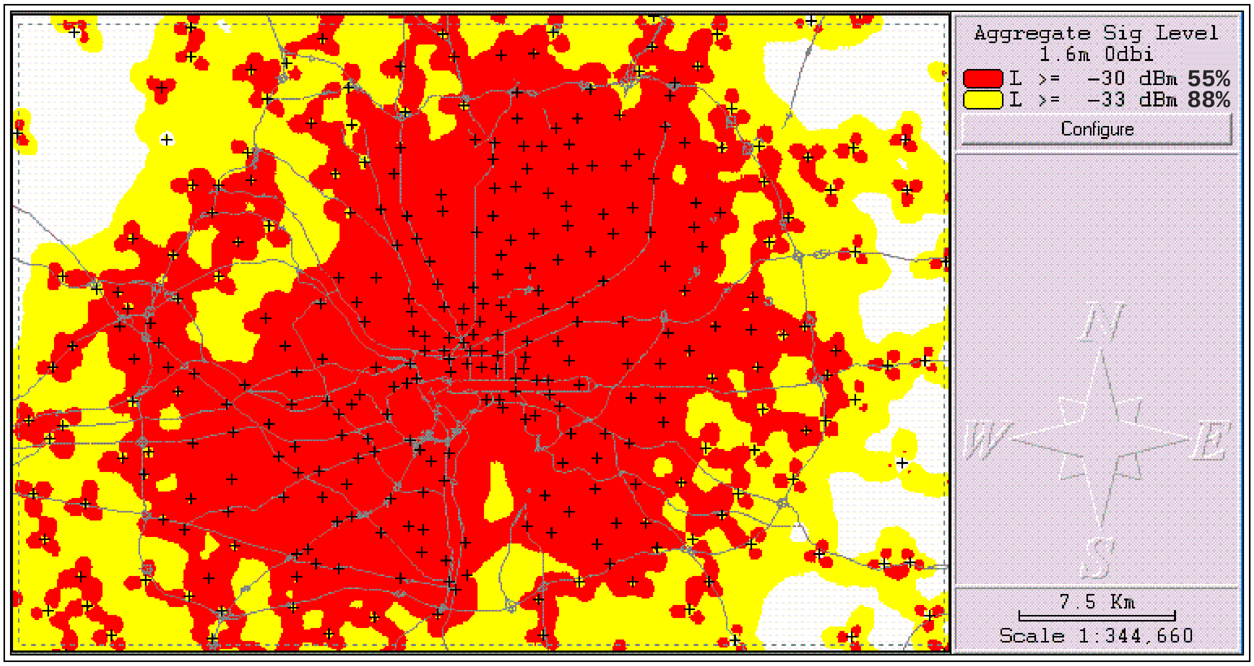
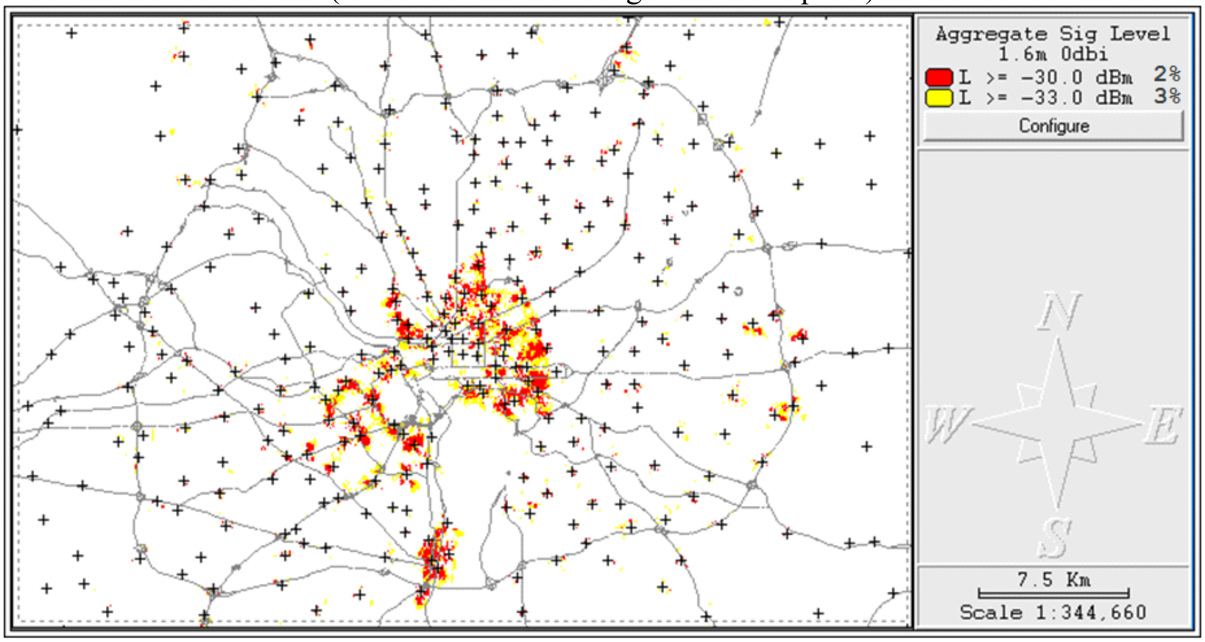


**Figure A.II.10 - Aggregated received signal level prediction (using Free Space Line of Site with clutter and terrain)**

(Sum of the received signals in each pixel)




*Clutter data within the most densely-populated areas is based on 1 meter resolution survey; in the surrounding area 30 meter resolution data is used*

In short, the use of ITM would impose an extraordinary burden on the operation of LightSquared's network without any rational technical justification in terms of additional protection to GPS receivers.

In contrast to ITM, WILOS is widely used to model propagation in open urban environments where there is line of sight to the base station. The WILOS model predicts greater loss than free space at distances greater than 20 meters and has been empirically verified to be a better predictor of the median value of RF power in urban environments with clear line of sight to the base station than a rudimentary free space model. Even though WILOS predicts less loss than the free space model, it is still inherently conservative as it ignores blockages. For this very reason, it is not generally used in planning RF coverage for communications networks, but can be a useful tool for where conservatism may be desired. By contrast, cellular RF planning is typically based *not* on line-of-sight models, but on non-line-of-sight models, such as WiNLOS, Hata-Okumura and COST231. In other words, using WILOS everywhere in the coverage footprint of a network would still significantly over-predict the RF power. Nevertheless, LightSquared is willing to accept the WILOS model as the basis for its Height-Power approach.

### B. NTIA improperly rejected the Measurement-Based approach

LightSquared's Measurement-Based approach comprised a detailed post-deployment measurement process to identify any hot spots that would be eliminated by reducing base station power as necessary. This approach was intended as an alternative to the theoretical basis that underlies NTIA's use of the ITM (and even LightSquared's proposed use of WILOS in its

Height-Power approach). NTIA, in its letter, does not even mention this proposal, let alone explain its rejection.

NTIA informally indicated that it did not believe that an adequate compliance mechanism could be developed for the Measurement-Based approach. This ignores the fact that nearly anyone that has the ability to operate rather rudimentary test equipment could audit LightSquared's power in the same manner in order to determine if LightSquared was in fact meeting its compliance requirements. This is contrasted to the traditional EIRP-based regulation, where it is impossible to determine compliance without access to carriers' secured communications equipment.

NTIA's insistence on the use of the ITM, with a maximum power threshold of -33 dBm would require LightSquared to construct thousands of additional cell sites in order to compensate for the reduced coverage footprint occurring as a result of reduced transmitter power. As has been demonstrated above, these power level reductions are well above those necessary to protect general location/navigation devices from experiencing receiver overload (which, again, is due to their own design deficiencies). Either of the LightSquared proposals (Height-Power or Measurement-Based) would achieve the stated goal of NTIA to ensure continued operation of GPS devices, but without imposing excessive additional costs to LightSquared over and above the amounts required for LightSquared to comply with the proposed solutions it has submitted. LightSquared has estimated that the cost of complying with the NTIA proposed thresholds would be over $9 billion higher than compliance with LightSquared's proposed solutions.

### C. LightSquared's proposed use of LHCP would have further mitigated any potential for overload

Finally, NTIA fails to address LightSquared's offer to use left hand circular polarization in its base station antennas, which would generate approximately 6 dB of additional margin relative to the use of dual linear polarization.[38] The reality is that significant potential exists for creating additional margin across all classes of GPS receivers through the use of some optimized set of base station antenna polarizations. These were presented by LightSquared, but never considered by NTIA.

Examples are provided below of antenna cross-polarization discrimination from two manufacturers of high precision GPS antennas. The measured data about Hemisphere antennas was provided to LightSquared by the manufacturer. The data about the Novatel antenna is publicly available in the manufacturer's data sheets.

[38] Antenna manufacturers estimate that there is over 15 dB of polarization isolation to be gained using LHCP antennas; LightSquared is using the 6 dB value in its analysis in order to account for environmental reflection and differences in antenna elevation angles.

**Figure A.II.11**

Measured Patterns for Hemisphere's
A52 Antenna at 1531 MHz

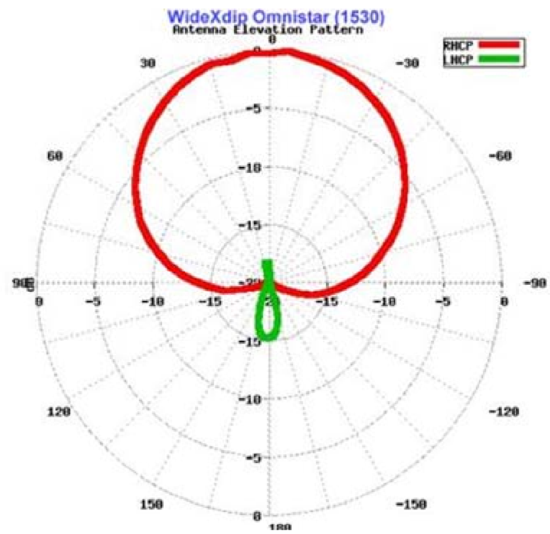



**Figure A.II.12**

Measured Patterns for Hemisphere's
A52 Antenna at L1 frequency

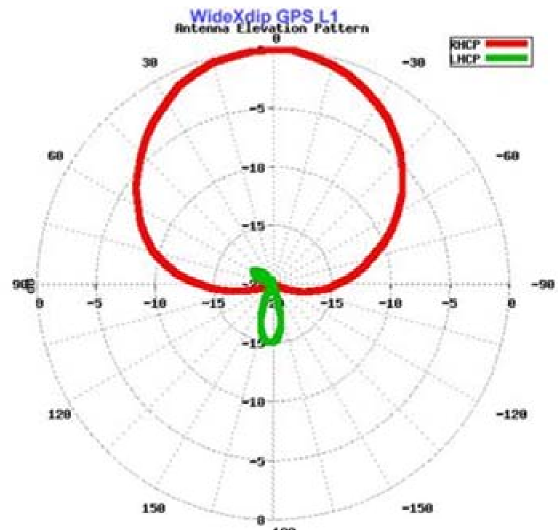
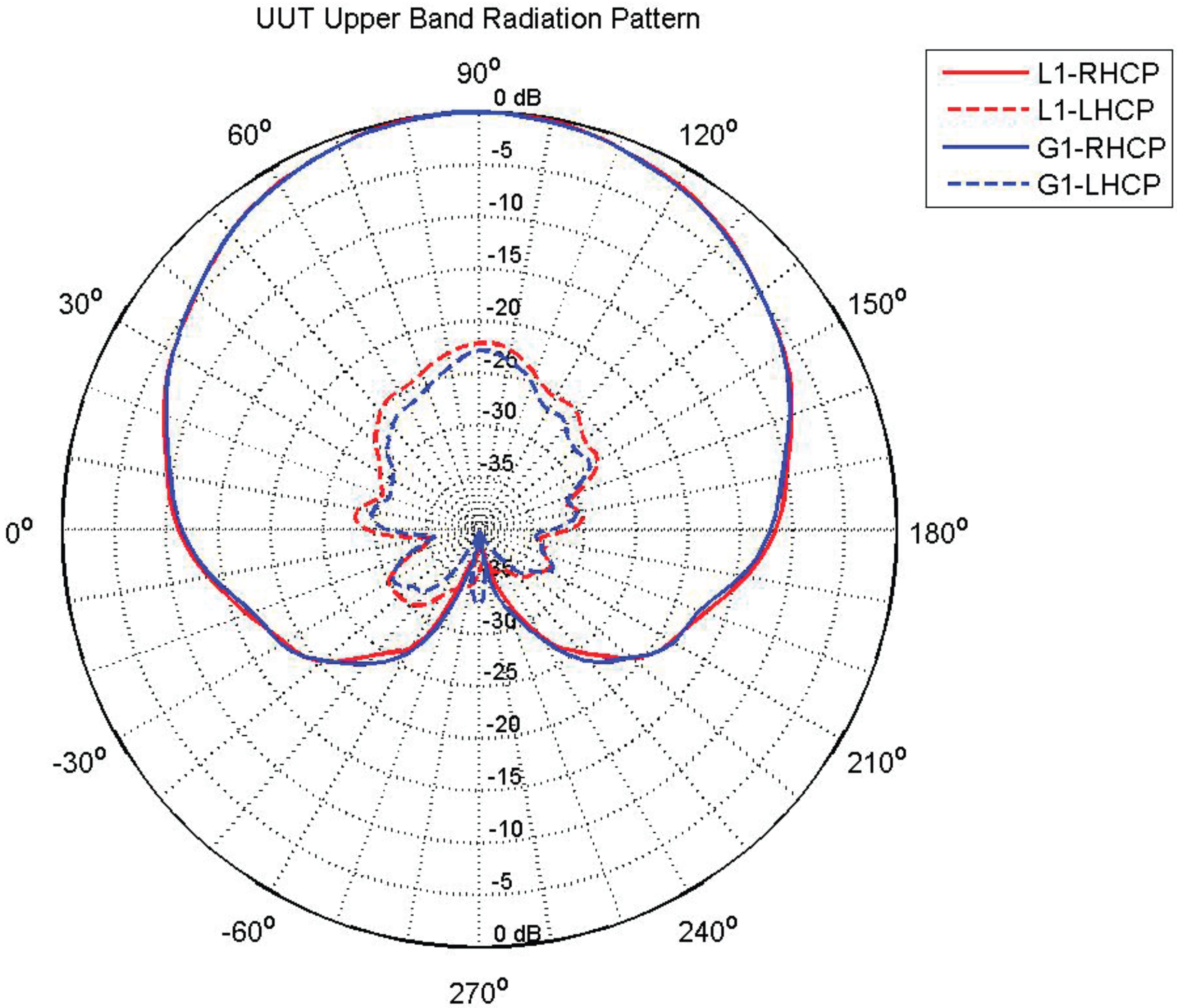


**Figure A.II.13 - Polar Patterns for Novatel Antenna (GPS-703-GGG)[39]**
**"G" refers to Glonass band response**




[39] Information available from public data sheets.

## III. THERE IS NO SCIENTIFIC BASIS FOR USING A LOSS OF 1 DB IN $C/N_0$ FOR TESTS TO DETERMINE THAT A PERSONAL/GENERAL NAVIGATION DEVICE WOULD BE INCOMPATIBLE WITH LIGHTSQUARED OPERATIONS

One of the major failures in the NTIA Letter [4] is its use of a standard for "harmful interference" to Personal/General Navigation devices that has no scientific support.[40] NTIA, however, ignores all of this without explanation.[41] In contrast to the NPEF tests, the tests of cellular devices sponsored both by the TWG and by NTIA specifically measured changes in position accuracy through a series of tests. The cellular tests showed all devices to be compatible with LightSquared operations.

As described further below, there is ample empirical and theoretical evidence that a loss of 1 dB in $C/N_0$ is not an indicator of loss of performance in a GPS device.

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[40] IEEE 1900.2 [13] makes clear that just because potential interference is measurable at a particular level does not mean that it constitutes "harmful interference." More specifically, IEEE 1900.2 [13] defines an "interference event" and "harmful interference" as follows:

**4.3 Interference event**

An interference event is a measurement event in which a source device or system has a quantifiable performance effect on the recipient device or system or for the user of a recipient device or system. The concept of an interference event is used in the analysis for determining the amount and severity of interference. Interference events are therefore a subset of the measurement events. An interference event is scenario dependent. Depending on the service, performance degradation can be manifested in many ways. An individual interference event may not in itself be deemed harmful. When interference events degrade performance to an unacceptable level from a service perspective, it is termed harmful interference.

**4.4 Harmful interference**

Harmful interference is the level at which the analysis deems interference events have created unacceptable interference. The level shall be defined in terms of interference events across time and/or users or systems that cause an unacceptable degradation of the recipient system's performance, in the judgment of the analyst. This threshold will be used when determining whether harmful interference has occurred. The analysis of a system may involve more than one threshold. The analysis shall state the reasons for selecting the harmful interference criteria used in the analysis.

Under this IEEE standard, a 1 dB $C/N_0$ degradation may be a measurable interference event, without constituting "harmful interference" for IEEE purposes. For IEEE purposes (putting aside legal and regulatory purposes), for that to occur, the data would need to show an actual loss of performance that is perceptible to the user and not something that is merely measurable.

[41] NTIA's only attempt to justify its use of 1 dB $C/N_0$ is its statements that it has used a 1 dB loss in $C/N_0$ in other situations to manage interference and its understanding that this was consistent with the power levels measured by the TWG. NTIA Letter [4]. The first statement is not scientifically relevant; if it was then doctors would still be bleeding patients to treat disease. The second statement is simply wrong; the issue of whether to use a 1 dB loss of $C/N_0$ was a very controversial one in the TWG. *See* LightSquared, Reply Comments, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (August 15, 2011) ("LightSquared Reply Comments [7]").

### A. The dynamic tests performed by the TWG showed that a 1 dB erosion of $C/N_0$ had little impact on the postion tracks as determined though statistical analyses

The most compelling data about the irrelevance of a 1 dB loss of $C/N_0$ came from dynamic tests that were developed by the TWG sub-team evaluating General Location and Navigation devices. These tests recorded live GPS signals in the field in a set of typical environments selected by the sub-team. These environments included dense urban, suburban, deep woods, and forest path locations. The recordings were made by Alcatel Lucent under the supervision of sub-team members and included other normal sources of degradation, such as non-LightSquared additive noise, multipath fading, and Doppler shift.[42] The recordings were rebroadcast in an anechoic chamber to conduct simulations of the impact on actual personal navigation receivers.[43] The LightSquared signal was added as a constant amplitude signal to the GPS signals recorded in the field and radiated toward the GPS receiver from the direction of maximum antenna gain.[44]

These results were then analyzed in conjunction with static tests in which constant power GPS signals from a GPS signal simulator and a constant power LightSquared signal were added together and radiated into the GPS receiver. The results show the LightSquared power levels at which the GPS receivers reported $C/N_0$ decreases at a range of values relative to the baseline of no LightSquared signal. Table A.III.1, reproduced from the TWG Final Report [17], presents that data for the static tests.

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[42] These sources of degradation are due to the existing RF and physical environment in which GPS devices operate. Most GPS devices have features to compensate for a temporary loss of signal so that the device can continue to operate as expected by the end user.

[43] As Garmin correctly noted, the laboratory tests were performed using a combination of a lower 5 MHz channel and an upper 5 MHz channel, rather than a single lower 10 MHz channel. Garmin International, Inc., Comments, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109, pp. 38-39 (August 1, 2011) ("Garmin Comments [8]"). For purposes of selecting an appropriate pass/fail criterion, however, this difference should not be relevant and, in any case, it is likely that the use of only the Lower 10 MHz channel would have shown less impact than that of the two channels.

[44] This methodology will yield very conservative results, since it ignores the fact that, as is the case for the GPS signals, the LightSquared base station signal will also suffer blockage and multipath fading, with a mean value that will be several dBs lower than used in the test. Additionally, the LightSquared signal will likely enter the GPS receiver at a lower elevation angle than the GPS signals and hence encounter lower antenna gain.

**Table A.III.1**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Phase 0b | | | | | | |
| | TEST: | Static InterferenceSuceptibility, downlink 1531.0 (10 MHz BW) | | | | | |
| | Power at Device (dBm) vs C/N degradation | | | | | | |
| | Device | 1 dB | 3 dB | 6 dB | 10 dB | 20 dB | LOF |
| 1 | P14949 | -33.0 | -26.0 | -21.0 | -15.0 | -8.0 | -3.0 |
| 2 | G15343 | -32.0 | -27.7 | -24.3 | -20.1 | -9.4 | -2.0 |
| 3 | G14298 | -29.5 | -22.5 | -17.5 | -14.6 | -8.6 | -6.6 |
| 4 | G18161 | -23.6 | -20.6 | -18.2 | -15.9 | -9.3 | -5.5 |
| 5 | G15028 | -23.5 | -19.7 | -14.5 | -10.5 | lof | -5.2 |
| 6 | G16382 | -22.0 | -13.0 | -9.0 | -8.0 | lof | -5.0 |
| 7 | G12586 | -19.7 | -15.6 | -12.7 | -8.8 | -3.5 | *MPNE* |
| 8 | G17641 | -13.7 | -9.7 | -8.7 | -4.6 | *MPNE* | |
| 9 | G12867 | -13.3 | -9.4 | -6.5 | -3.0 | *MPNE* | |
| 10 | G10195 | -9.6 | -6.4 | 4.0 | *MPNE* | | |
| 11 | G12559 | -9.5 | -3.8 | *MPNE* | | | |
| 12 | P15427 | -8.0 | -5.0 | -3.0 | *MPNE* | | |
| 13 | G10968 | -7.5 | *MPNE* | | | | |
| 14 | G18062 | -7.3 | *MPNE* | | | | |
| 15 | G15448 | -5.2 | *MPNE* | | | | |
| 16 | G13445 | -5.1 | *MPNE* | | | | |
| 17 | G16534 | -4.0 | *MPNE* | | | | |
| 18 | G17169 | -3.5 | *MPNE* | | | | |
| 19 | G11207 | -3.4 | *MPNE* | | | | |
| 20 | P17655 | -2.0 | *MPNE* | | | | |
| 21 | G10607 | *MPNE* | | | | | |
| 22 | G14188 | *MPNE* | | | | | |
| 23 | G14666 | *MPNE* | | | | | |
| 24 | G16449 | *MPNE* | | | | | |
| 25 | G17783 | *MPNE* | | | | | |
| 26 | G18696 | *MPNE* | | | | | |
| 27 | P13275 | *MPNE* | | | | | |
| 28 | P14730 | *MPNE* | | | | | |
| 29 | P18892 | *MPNE* | | | | | |
| | | *MPNE* | Maximum Power reached with No Effect (> 0 dBm) | | | | |

LightSquared mapped the results of the static tests to the actual drive test routes, which it presented in a series of figures highlighting the variation in performance for three cases: (i) no LightSquared signal; (ii) a LightSquared signal causing a 3 dB decrease in $C/N_0$; and (iii) a LightSquared signal causing a 6 dB decrease in $C/N_0$. Copies of those maps are in LightSquared's Reply Comments [7].[45] The maps show no significant difference among the three cases. In the best case, the receivers performed very well and in the worst case (Dense Urban), performance fluctuated significantly (presumably due to the low GPS signal availability), but was generally no worse in the 6 dB case, and sometimes actually appeared to be better owing presumably to the random nature of the position errors. LightSquared also performed a statistical analysis of the position errors relative to estimated true positions. The analysis was performed for the baseline case of no LightSquared signal, as well as the cases where a LightSquared signal of the power level corresponding to a 6 dB decrease in $C/N_0$ (in the static tests) is added.[46] The results show no meaningful variation in position accuracy statistics between the baseline and 6 dB cases. In the Dense Urban environment, the position accuracy

[45] LightSquared Reply Comments [7], at Appx. Exh. A.

[46] LightSquared Reply Comments [7], at Appx. Exh. B.

was relatively poor for both cases, with a great deal of variability, and in the Suburban environment, it was routinely excellent for both cases.

### B. It is well understood that 1 dB loss of $C/N_0$ is a very small fraction of the link margin that GPS receivers carry

GPS signal powers received on the ground are not static but time-varying. The reasons a GPS signal power changes incude: variable shadow/blockage conditions, especially for low elevation satellites, movement of the GPS device or people using the device and multipath (always present). Javad GNSS, a GPS manufacturer, has explained why high precision receivers need to carry operating margin to deal with GPS signal variability.[47]

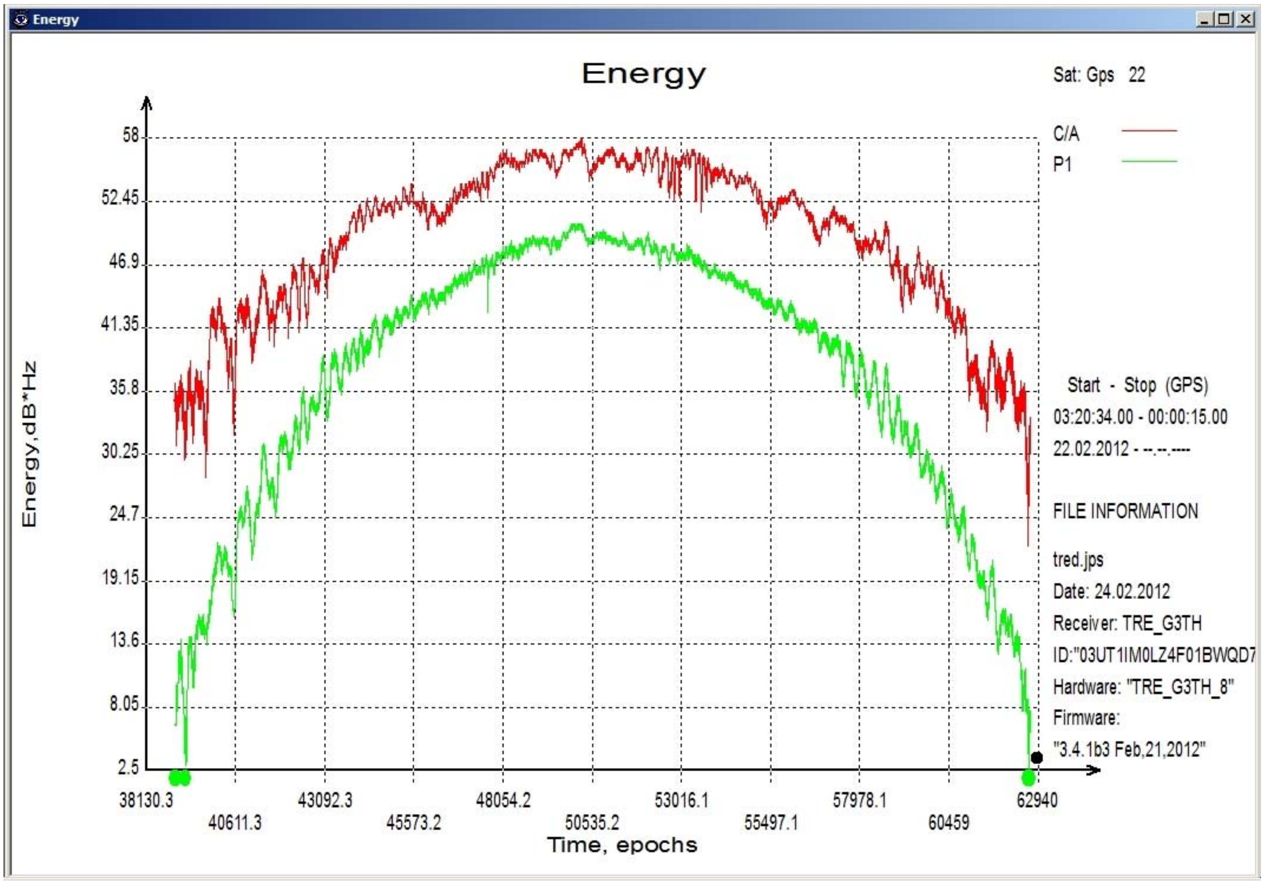
Typically, High Precision receivers report a $C/N_0$ of around 50 dB.Hz and can maintain tracking down to approximately 20 dB.Hz and lower, depending on particular receiver design. The erosion of 1 dB in this 30 dB dynamic range is not expected to have a significant operational impact. The reason for this large dynamic range is that for precision positioning accuracy, the most important factor is Geometric Dilution of Precision (GDOP). A good GDOP is achieved when the geometry of satellites provide the largest possible tetrahedron. This in turn requires the use of satellites that are in lower elevation angles. Satellites with lower elevation angles have lower $C/N_0$ but the receiver is required to process signals at this lower $C/N_0$ with no loss of position accuracy. US Geodetic Survey recommends 15 degree elevation as the cutoff threshold for satellites because (signals from) satellites lower than 15 degree suffer from (excessive) ionospheric and tropospheric effects. At 15 degree elevation, receivers encounter over 35 dB Hz $C/N_0$. So, receivers conforming to the US Geodetic Survey recommendation need to carry at least 15 dB of margin relative to 50 dB.Hz. In practice, many receivers can track down to 20 dB.Hz, i.e. carry 30 dB headroom. Given this large dynamic range, a 1 dB erosion of C/N0 has no effect on the practical accuracy of results. In other words, a 1 dB erosion of the margin, *a small percentage of the time* (under 1% as per LightSquared's deployment plan) would rarely, if ever, impact the user experience.[48]

The following graph shows an example of the variation of $C/N_0$ over time, measured with a fixed GPS receiver over a 20 hour 40 minute period. It is clear that, over this period, there was an approximately 20 dB variation in the $C/N_0$ for the C/A code for the reasons suggested above. There are also short term variations of 3-6 dB riding on the long term varaition mentioned above. Given both the short and long term variations inherent in the received $C/N_0$, it is inconceiveable that a 1 dB downward movement in the entire $C/N_0$ curve (the result of a 1 dB degradation of $C/N_0$) could be perceptible by a user. The $C/N_0$ variation with mobility is even greater, making a 1 dB $C/N_0$ degradation even less visible.

[47] *See* Javad, "GPS C/N0 variations" (March 15, 2012) *available at* http://www.javad.com/jgnss/javad/news/pr20120315.html ("Javad C/N0 Analysis [9]").

[48] Javad C/N0 Analysis [9].

**Figure A.III.1 - Typical variation of GPS $C/N_0$ received on the ground with a fixed antenna**




A theoretical examination of GPS position error budgets provides further support that, under normal operating conditions, a 1dB loss should have no more than a very small impact on code tracking and carrier-phase tracking and no noticeable impact on performance from the user's perspective.

### 1. Code tracking performance in noise environment.

The GPS receiver code tracking loop, or delay lock loop (DLL), is a dominant source of range measurement errors, and its sensitivity to thermal noise is highly dependent on receiver architecture. According to Kaplan,[49] for modern generic GPS receiver architecture - the DLL with early/late discriminator, thermal noise tracking root-mean-squared (RMS) error is:

$$\sigma_{DLL}\,(chips) = \{\, 2d^2 B_L / (C/N_o)\ [2(1 - d) + 4d / (T\ C/N_o)]\ \}^{0.5}$$

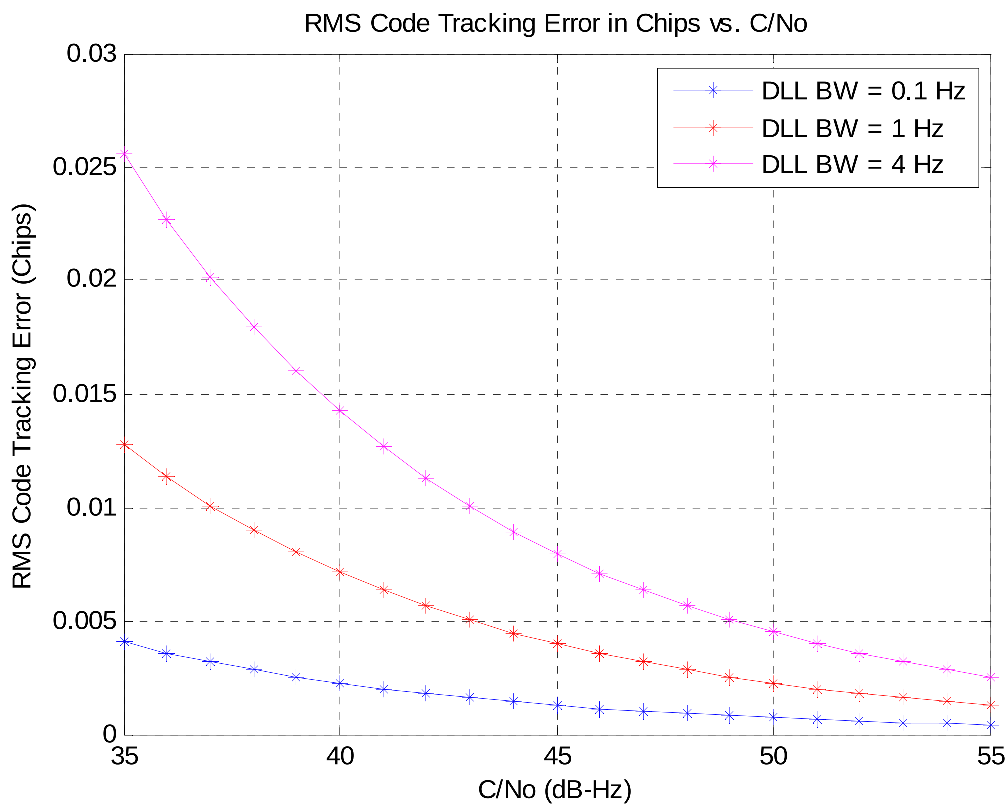
[49] Kaplan, E. D. and Hegarty, C., Understanding GPS Principles and Applications (2 Ed.), Artech House, 2006 ("Kaplan *et al.* [10]").

where $d$ is the early-to-late correlator spacing normalized with respect to one chip, $B_L$ is the code loop bandwidth in Hz, $C/N_0$ is the carrier-to-noise ratio in linear unit, and $T$ is the pre-detection integration time in seconds.

Figure A.III.2 plots the DLL code tracking error as a function of $C/N_0$ for $d = ½$ , and $T$= 20 ms with three code loop bandwidths. The tracking error appears to be proportional to the loop bandwidth. By changing the $C/N_0$ level from 35 dB-Hz to 55 dB-Hz, the RMS error ranges from 0.0125 chip at low $C/N_0$ to 0.001 chip at high $C/N_0$ for the 1 Hz loop bandwidth case. The code tracking error in chip can be readily converted to meters by using 293m/chip for C/A-code, and 29 m/chip for P(Y) code.

An example shows that code tracking performance degradation by 1 dB $C/N_0$ reduction is small. Taking $C/N_0$ = 46 dB to $C/N_0$ = 45 dB, the RMS code tracking error is changed from 0.0035 chip to 0.004 chip for the loop bandwidth = 1 Hz, which is a difference of only 0.004-0.0035 = 0.0005 chip which is equivalent to 0.1167m - 0.1040m = 0.0145m for P(Y) code and 0.145 m for C/A code.

**Figure A.III.2 – RMS Code Tracking Error versus C/No**



## 2. Carrier-phase tracking performance in noise environment.

For the Carrier-phase tracking loop, or phase lock loop (PLL), the PLL thermal noise is treated as the only source of carrier tracking error. According to Kaplan, the PLL is implemented in the form of a Costa loop and the RMS tracking error can be computed as

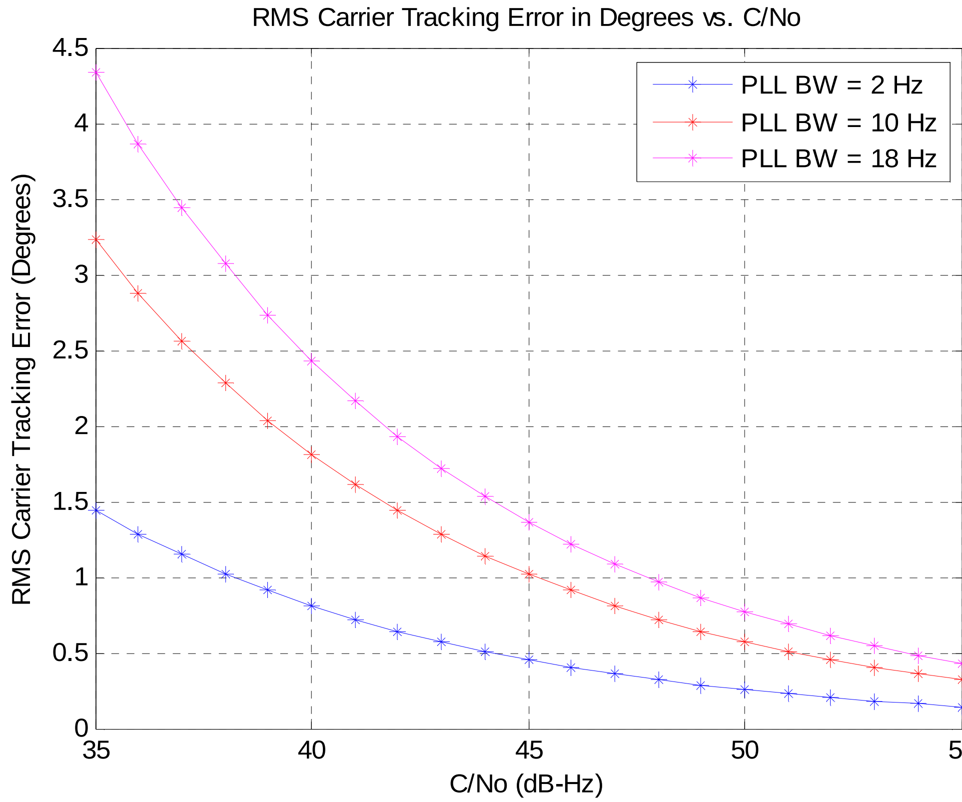
$$\sigma_{DLL}\,(Degrees) = 360 / 2\pi \,\{ B_L / (C/N_o)\, [1 + 1 / (2T\, C/N_o)]\}^{0.5}$$

Where $B_L$ is the PLL loop bandwidth in Hz, $C/N_0$ is the carrier-to-noise ratio in linear unit, and $T$ is the pre-detection integration time in seconds.

A plot of the RMS carrier tracking error versus $C/N_0$ is given in Figure A.III.3 for $T$ = 20ms with $B_L$ = 2Hz, 10Hz, and 18Hz. It can be seen that the carrier tracking error is dependent on $C/N_0$, the tracking loop bandwidth for a given integration time. For the PLL bandwidth = 2Hz, the RMS carrier tracking error is ranged from 1.45˚ to 0.14˚ when $C/N_0$ is varied from 35 dB-Hz to 55 dB-Hz. For the L1 carrier (wavelength of 0.19m), the tracking error can be readily converted to the meter scale, which is ranged from 0.76mm to 0.08mm.

For $C/N_0$ 1 dB degradation, for example, from 46 dB-Hz to 45 dB-Hz, the RMS carrier tracking error is changed from 0.41˚ to 0.45˚ for the loop bandwidth = 2 Hz. For the L1 carrier, the difference is only 0.45-0.41 = 0.04˚, which is equivalent to 0.02mm. Thus, the carrier tracking performance degradation by the 1 dB $C/N_0$ reduction is extremely small.

**Figure A.III.3 - RMS Carrier-phase Tracking Error versus C/No**




### 3. Receiver Tracking Error and Overall Pseudorange Error Budgets for Precision and Standard Positioning Services.

The total system UERE (User-equivalent range error) is determined by overall pseudorange error budgets, which include not only receiver tracking error, but also many other error sources as well. The total system UERE budget comprises components from each system segment: the space/control segment, and the user segment. Tables A.III.2 and A.III.3 give the estimates of typical contemporary UERE budgets for Precision Position Service (PPS) and Standard Position Service (SPS) respectively, as provided by Kaplan and Hegarty.[50]

The PPS budget Table A.III.2 is for a dual-frequency P(Y) code receiver, and the SPS budget Table A.III.3 is for a single-frequency C/A code receiver.

[50] Kaplan *et al.* [10], at chapter 7.

**Table A.III.2 - GPS PPS Typical UERE Budget**

| Segment Source | Error Source | 1σ Error (m) |
|---|---|---|
| Space/control | Broadcast clock | 1.1 |
| | Broadcast ephemeris | 0.8 |
| User | Residual ionospheric delay | 0.1 |
| | Residual tropospheric delay | 0.2 |
| | Receiver noise and resolution (**Receiver tracking error**) | 0.1 |
| | Multipath | 0.2 |
| System UERE | Total (RSS) | 1.4 |

**Table A.III.3 - GPSPS Typical UERE Budget**

| Segment Source | Error Source | 1σ Error (m) |
|---|---|---|
| Space/control | Broadcast clock | 1.1 |
| | Broadcast ephemeris | 0.8 |
| | L1 P(Y) – L1 C/A group delay | 0.3 |
| User | Ionospheric delay | 7.0 |
| | Tropospheric delay | 0.2 |
| | Receiver noise and resolution (**Receiver tracking error**) | 1.0 |
| | Multipath | 0.2 |
| System UERE | Total (RSS) | 7.2 |

The RSS (root-sum-squared) addition of UERE components is computed by assuming each of the errors is independent random variables with the following formulas

$$\sigma_{UERE}\,(m) = (\sigma_1^2 + \sigma_2^2 + \cdots + \sigma_N^2)^{0.5}$$

As discussed above, in studying the receiver tracking error, it is apparent that the code tracking residual error is dominant. The first example showed that at $C/N_0$ = 46 dB-Hz the receiver tracking error is 0.104m for P(Y) code, which is about the same as the 0.1m booking in Table A.III.2. Also at $C/N_0$ = 46 dB-Hz the receiver tracking error for C/A code is 1.04m, which is booked in Table A.III.3. At $C/N_0$ = 45 dB-Hz the receiver tracking error is 0.1167mfor the P(Y) code PPS receiver. By replacing 0.1 m receive tracking error with 0.1167 m, the total system UERE is $\sigma_{UERE}\,(m) = (1.1^2 + 0.8^2 + 0.1^2 + 0.2^2 + 0.1167^2 + 0.2^2)^{0.5}$ = 1.4 m for PPS. Similarly, for the C/A code SPS receiver, at $C/N_0$ = 45 dB-Hz the tracking error is 1.167m. By replacing 1 m receiver tracking error with 1.167m, the total system UERE is

$\sigma_{UERE}\,(m) = (1.1^2 + 0.3^2 + 0.8^2 + 7.0^2 + 0.2^2 + 1.167^2 + 0.2^2)^{0.5}$ = 7.2 m for SPS.

Therefore, the 1 dB C/No degradation has no practical impact on the GPS accuracy for both PPS and SPS.

With these two system UEREs, we can determine the GPS accuracy for both PPS and SPS. The magnitude of the horizontal error is given by circular error probability (CEP), which is defined as the radius of the circle that when centered at the error-free location includes 50% of the error distribution, by using an average global HDOP of 1 with $\sigma_{UERE}$ = 1.4m for PPS, and $\sigma_{UERE}$ = 7.2 m for SPS

$CEP_{50} = 0.75*HDOP*\sigma_{UERE} = 0.75x1x1.4 = 1.1m$ *for PPS*
$CEP_{50} = 0.75*HDOP*\sigma_{UERE} = 0.75x1x7.2 = 5.4m$ *for SPS*

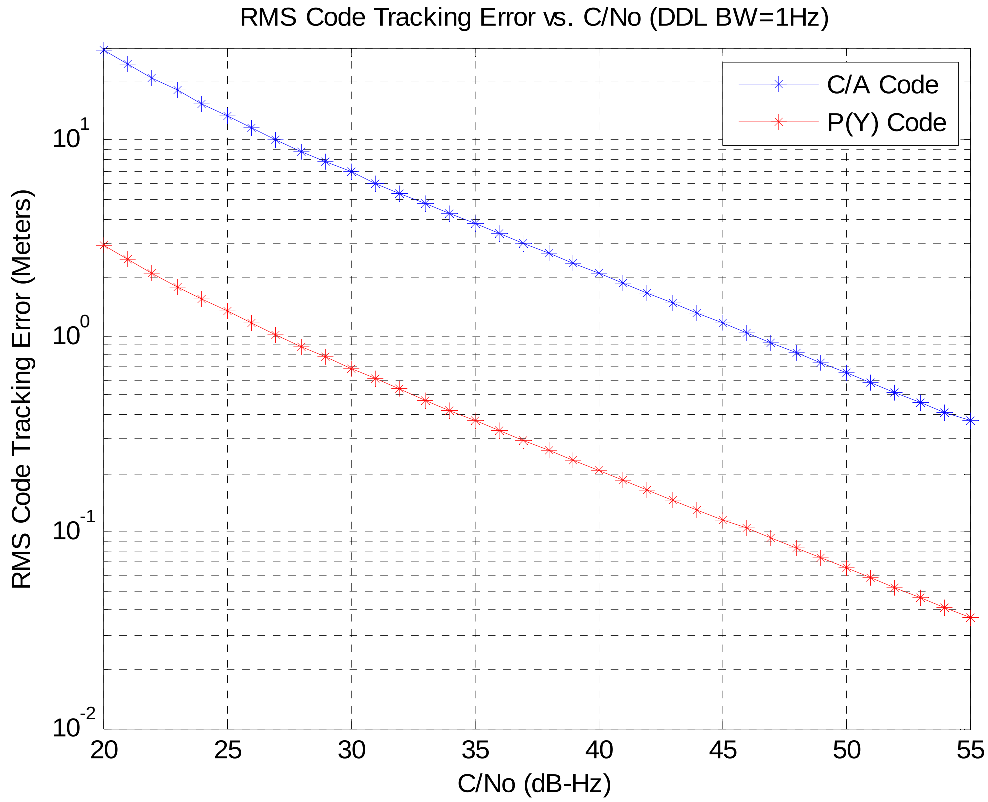
We can also examine how much $C/N_0$ degradation would be needed in order to have 1 m increase of $CEP_{50}$. This is $CEP_{50} = 1.1 +1 = 2.1m$ for PPS and $CEP_{50} =5.4+1 = 6.4m$ for SPS, which would lead to $\sigma_{UERE} = 2.1/0.75 = 2.9m$ for PPS*, and* $\sigma_{UERE} = 6.4/0.75 = 8.5m$ for SPS. By assuming that all error sources remain the same except for the receiver tracking error, we can obtain the new receiver tracking errors

$\sigma_{DLL}(m) = [2.9^2 - ( 1.1^2 + 0.8^2 + 0.1^2 + 0.2^2 + 0.2^2) ]^{0.5}$= 2.5 m for PPS, and

$\sigma_{DLL}(m) = [8.5^2 - ( 1.1^2 + 0.3^2 + 0.8^2 + 7.0^2 + 0.2^2 + 0.2^2) ]^{0.5}$= 4.6 m for SPS.

Figure A.III.4 shows the code tracking error in meters for both P(Y) and CA codes with loop bandwidth of 1 Hz as a function of $C/N_0$. From this figure, $C/N_0$ values would be about 21 dB-Hz for 2.5 m error for P(Y) code PPS, and about 33 dB-Hz for 4.6 m error for C/A code SPS. <u>These $C/N_0$ numbers correspond to 46 -21 = 25 dB $C/N_0$ degradation, and 46 – 33 = 13 dB $C/N_0$ degradation respectively</u>.

**Figure A.III.4 - RMS Code Tracking Error in meters versus C/No**




Again, this confirms that a 1 dB $C/N_0$ degradation in the GPS receiver would not be expected to have a noticeable impact on the user experience.

### C. TWG Cellular KPI Tests used a different metric

In stark contrast to the general location/navigaton industry, the cellular industry has well establshed, detailed performance metrics and test procedures by which it is able to objectively assess the performance of the devices that it sells to its customers. Rather than rely on an overly simplistic, and largely irrelevant metric (such as 1 dB $C/N_0$), the cellular industry relies on a series of thorough, statistically significant tests that correlate to actual device performance. The TWG cellular testing was based on these recognized industry standards and stayed as close as possible to the following:

- 3GPP 34.171: AGPS Minimum Performance for WCDMA/HSDPA devices (suitable for connectorized testing of 3GPP devices)[51]
- TIA-916: AGPS Minimum Performance for CDMA devices (suitable for connectorized testing of 3GPP2 devices)[52]

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[51] 3rd Generation Partnership Project, Technical Specification 34.171, V9.3.0 (September 2009) ("3GPP 34.171 [11]").

[52] Telecommunications Industry Association, TIA Standard Recommended Minimum Performance Specification for TIA/EIA/IS-801-1 Spread Spectrum Mobile Stations, TIA-916 (April 2002) ("TIA-916 [18]").

- CTIA v3.1: AGPS Radiated test plan for CDMA and WCDMA/HSDPA devices: suitable for radiated testing (in a chamber) of both 3GPP and 3GPP2 devices[53]

These industry standards call for a number of Key Performance Indicators (KPIs) to be measured during testing. The primary KPI is position error, which was chosen to enable passing of the FCC's E911 requirements. For example, the Nominal Accuracy Test in the 3GPP tests[54] requires the test to demonstrate a position error less than 30 m with 95% confidence factor over a large number of repetitions of the test; the Sensitivity Test requires the position error to be less than 100 m, also with 95% confidence.[55] These may be compared with E911 reqirements:

> The FCC's accuracy and reliability requirements for automatic location information (ALI) for wireless carrier enhanced 911 (E911) service require that carriers using handset-based E911 solutions provide location information within 50 meters for 67 percent of calls and within 150 meters for 95 percent of calls.[56]

In contrast, the 1 dB $C/N_0$ desense threshold is not related to any application driven metric nor are there any standards about how it should be measured.

Unlike the 1 dB threshold criterion, the cellular standards require many receiver performance metrics to also be monitored. As an example the TIA-916 sensitivity testing requirements are shown:

[53] CTIA Test Plan [2], at p. 137.

[54] 3GPP 34.171 [11], at Section 5.3.2.

[55] 3GPP 34.171 [11], at Section 5.2.1.2.

[56] These are the historical requirements for handset based location and there are recently adopted rules, 47 C.F.R. Part 20.18 which will reflect different standards in the coming years

**Table A.III.4 – TIA 916 Table 2.1.1.3.3-1 Minimum Standards**

**Table 2.1.1.3.3-1 Minimum Standards for the GPS Sensitivity Test**

| Mobile Station Response | Parameter Field | Limit Parameter | Limit Value |
|---|---|---|---|
| *Provide MS Information* | N/A | $T_1$ | 750 ms |
| *Provide Pseudorange Measurement* | SV_CODE_PH_WH<br>SV_CODE_PH_FR | $N$ | 4 |
| | | $T_2$ | 16 s |
| | | $CODE_{1R}$ | 0.11 GPS chips |
| | | $CODE_{2R}$ | 0.33 GPS chips |
| | | $CODE_{1A}$ | 0.31 GPS chips |
| | | $CODE_{2A}$ | 0.63 GPS chips |
| | PS_DOPPLER | $DPR_1$ | 40 Hz |
| | | $DPR_2$ | 80 Hz |
| | SV_CNO | $CNO_1$ | 4 dB-Hz |
| | | $CNO_2$ | 6 dB-Hz |
| | PS_RANGE_RMS_ER | $R_1$ | 0 |
| | | $R_2$ | 3 |
| *Provide Location Response* | LAT<br>LONG | $N$ | 1 |
| | | $T_2$ | 16 s |
| | | $LATLONG_1$ | 60 m |
| | | $LATLONG_2$ | 180 m |

As can be seen, seventeen performance indicators are monitored for this test. Similar required KPIs are listed for the other TIA tests. These standards also require significant averaging of the readings in order to insure that a stable reading, with an acceptable measurement uncertainty be achieved. The CTIA Test Plan states:

> The pattern data shall be determined by averaging Carrier-to-Noise ($C/N_0$) measurements at each point on the sphere. The C/N0 measurements will be obtained from the TIA-916 GPS accuracy test. For one measurement report, the reported satellite C/N0 values shall be averaged. If it is necessary to obtain more measurements to reduce uncertainty, repeat the measurement requests at the same position and polarization and independently average the reported satellite C/N0 values for each measurement report. After a sufficient number of measurement

requests have been made, average the average results that were obtained for each measurement request. Sufficient averaging shall be completed to ensure that the uncertainty is less than the value included in the uncertainty budget.[57]

In the cellular tests, each device was exposed to a range of signal levels from the LightSquared signal. The range from nothing detectable to full loss of signal was mapped. It was common to see a 10 to 20 dB range from first detectable influence from the LightSquared signal to total loss of GPS signal. The typical observation was that real impact from the LightSquared signal did not occur until well into this range. At the first detectable influence from the LightSquared signal, the other KPIs were usually unchanged or well within acceptable levels.

An important reason to monitor multiple KPIs is to insure that the test is proceeding accurately. As has been stated, typically there is a progression of influence with KPIs degrading as a function of the LightSquared signal and finally losing all GPS signals. This is true for devices that showed sensitivity, which was much more common with the upper band signal than for the lower band signal. Occasionally anomolous behavior was noted, such as the sudden loss of all KPIs. In these cases invariably it was discovered that some test related malfunction had occurred, most commonly the battery running low.

Monitoring multiple KPIs is essential to gain a true picture of the potential impact of the LightSquared signal. Moreover, it is important to prequalify the device being testing and average out its reading variability in order to get stable, repeatable test results.

The cellular tests also account for external received noise through the requirement that the simulated GPS signal have a $C/N_0$ of 44 dB.Hz.[58] If there were no need to emulate external noise in the tests, a transmit $C/N_0$ would not be specified.

### D. Other non-cochannel standards allow for a larger degradation without any adverse impact on receiver performance

The 3GPP standard for LTE specifies that, when testing for performance in the presence of an out-of-band blocking signal, the desired signal shall be increased by 6 dB above its sensitivity level. This is equivalent to creating an additional 6 dB margin, which may be used to accommodate the adjacent-band signal.[59]

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[57] CTIA Test Plan [2], at p. 137.

[58] *See* 3rd Generation Partnership Project, Recommended Minimum Performance Specification for Mobile Stations with Position Service, 3GPP2 C.S0036-0 Version 2.0, Section 2.1.1.1.2 (January 29, 2010) (3GPP2 C.S0036-0 [22]”).

[59] *See* 3rd Generation Partnership Project, Technical Specification 36.101, V9.10.0 (March 2010) (“3GPP 36.101 [19]”).

## IV. EVEN LIMITED TO THE MOST OBVIOUS ERRORS IN THE TESTING AND ANALYSIS, THERE IS NO EVIDENCE THAT ANY QUALIFIED DEVICES ACTUALLY ARE INCOMPATIBLE WITH LIGHTSQUARED OPERATIONS

Putting aside the many problems with the NPEF testing that cannot be definitively assessed retroactively, such as the biased selection process, the lack of controls, and the missing information, focusing solely on the obvious errors demonstrates that NTIA cannot reliably conclude that the performance of any of actual personal/general navigation devices tested was perceptibly degraded in a fair test. Table A.IV.1 below lists each of the devices that, based on LightSquared's best reading of the available data, NPEF characterizes as failing. The devices are listed in descending order of the point at which they recorded a 1 dB loss in C/No.

There are several ways to slice the results to see that there is no solid evidence that any of true consumer devices actually "failed." The key deficiency in NTIA's analysis is its use of -15 dBm as the threshold for compatibility. As discussed more fully in Section II above, NTIA has provided no support for rejecting LightSquared's commitment to operate at no more that -30 dBm initially. Accounting for that factor alone means that another 53 devices would have "passed." Accounting for the extra 6 dB from LHCP operation and using a more reasonable 6 dB loss in C/No would cause all but five devices to "pass." Proper accounting for environmental noise (up to 2.6 dB improvement) and antenna orientation (up to 6 dB improvement), might have caused even the few remaining devices to pass. Both the NPEF and TWG results show that there is at least a dB-for-dB relationship between the adjacent band power and $C/N_0$ degradation, and in many cases an increase of more than 1 dB of adjacent power is required to cause an incremental 1 dB degradation in $C/N_0$.[60]

Another way to view the results is to disqualify all the devices that supposedly failed that are not truly personal/general navigation devices. The worst-performing device appears to actually be a high-precision device. Several of the other devices are modules or subsystems, whose performance is not necessarily indicative of the performance of the complete, off-the-shelf consumer devices that were to be tested. One was actually a cell phone.

Finally, a moderately close review of the available data shows that many of the devices that were tested produced results that, without further explanation, must be disregarded. As displayed in Table A.IV.1, a large number of the devices that supposedly failed showed an abnormally low quiescent $C/N_0$, which on its face indicates either that the antenna was improperly oriented or the device was otherwise malfunctioning. Many devices also showed inconsistent results in each of the three repetitions. Again, without some reasonable explanation, these results should be discarded as indicative of something unreliable in the tests or the devices. Finally, six of the devices that "failed" showed a much different result in the TWG tests, another inconsistency that, without explanation, invalidates the results.

[60] *See* Exhibit A, Section I, Figures A.I.3-A.I.7.

**Table A.IV.1**

| Model ID No. | Avg power at which devices experienced 1 dB loss of $C/N_0$ (per graph) | Defect in selection | Defect in Quiescent $C/N_0$ (extent below 45 dB, Hz, in dBs) | Inconsistent results among each of three repetitions (in dBs) |
|---|---|---|---|---|
| 350 | -53.5 | High Precision | | 4.5 |
| 328 | -46.1 | Discontinued | 7 | 2.2 |
| 366 | -45.4 | Discontinued | 2.19 | |
| 347 | -45.1 | | 8 | 4 |
| 104 | -42.1 | | 1.01 | |
| 247 | -40.9 | Incomplete Device, Discontinued | | 1.9 |
| 206 | -38.8 | | 2.99 | 3.1 |
| 115 | -38 | | | 3.7 |
| 125 | -34.4 | Discontinued | 3.04 | 1.7 |
| 359 | -33.7 | | | 1.6 |
| 393 | -33.6 | Discontinued | 5.03 | 3.7 |
| 313* | -33.5 | | 11 | 4.3 |
| 249 | -32.9 | Discontinued | 1.43 | |
| 248 | -31.4 | Discontinued | | |
| 332 | -31 | | | 1.2 |
| 318 | -30.3 | | | |
| 373 | -30.1 | | | 2.7 |
| 235 | -29.8 | Incomplete Device, Discontinued | 1.82 | 1.7 |
| 211* | -29.5 | | 6.92 | |
| 320 | -29.4 | Discontinued | 9 | |
| 368 | -28.8 | | 5.98 | 5.8 |
| 208 | -28.2 | | 6.99 | |
| 336 | -28.1 | Discontinued | 1.01 | |
| 112 | -28 | | | |
| 333 | -28 | Incomplete Device | 1 | 1.7 |
| 360 | -27.9 | Incomplete Device | | 1.9 |
| 388 | -27.2 | | 8.12 | 2.2 |
| 134 | -26.6 | | 4.4 | |
| 218 | -26.1 | Discontinued | | |
| 358 | -25.3 | Discontinued | 2.91 | 1.1 |
| 371 | -25.1 | | 4.99 | |
| 100 | -24.7 | Discontinued | 4.2 | |
| 317 | -24.4 | Discontinued | 1.48 | |

| | | | | |
|---|---|---|---|---|
| 334 | -23.6 | | | 1.3 |
| 207 | -23.4 | | 3.04 | 2.3 |
| 232 | -23.3 | Incomplete Device | 1 | 1.7 |
| 105 | -23.2 | Incomplete Device | 3 | 1.2 |
| 341 | -22.7 | High Precision, Discontinued | | 1.9 |
| 389 | -22.6 | Discontinued | | |
| 316 | -22.5 | | 2.93 | 1.7 |
| 131 | -21.4 | | | 1.2 |
| 201 | -21.4 | | 2.61 | |
| 301 | -21.4 | | 2.85 | |
| 342 | -21.4 | Discontinued | 6.07 | |
| 302 | -21.2 | | 1.1 | |
| 123 | -21 | | | 1.1 |
| 397 | -20.9 | Discontinued | 3 | 6.3 |
| 314 | -20.8 | Discontinued | | |
| 325 | -20.7 | | 2 | 1.8 |
| 354 | -20.5 | Discontinued | 3.01 | |
| 374 | -20 | | 5.91 | |
| 326 | -19.3 | | 3.54 | |
| 324 | -18.9 | Discontinued | 4.98 | 1.1 |
| 396 | -18.8 | | | |
| 390 | -18.6 | | 2.33 | |
| 364 | -18.3 | | | |
| 307 | -18 | Incomplete Device | 10.03 | 1.9 |
| 110* | -17.8 | Discontinued | 13.14 | 1.5 |
| 120 | -17.5 | Discontinued | | |
| 379 | -16.9 | | | 1.2 |
| 204* | -16.7 | Incomplete Device | 13.07 | 1.1 |
| 375 | -16.4 | | | |
| 356* | -16.3 | | | 1.2 |
| 386 | -16.3 | | 2.01 | |
| 107 | -16.1 | | | |
| 124* | -16.1 | | | |
| 338 | -16.1 | | 1.02 | |
| 203 | -15.9 | | 2.67 | |
| 383 | -15.9 | Incomplete Device | 8.08 | |
| 377 | -15.8 | Cell Phone | 15.94 | |
| 327 | -15.4 | Incomplete Device | 7.99 | 2.4 |
| 127 | -15.3 | Incomplete Device | 9.7 | |
| 212 | -15 | | 1 | 2.1 |

* NPEF tests inconsistent with TWG tests of the same device

**References**


[1] National Space-Based Positioning, Navigation, and Timing Systems Engineering Forum (NPEF), Follow-on Assessment of LightSquared Ancillary Terrestrial Component Effects on GPS Receivers, (January 6, 2012).

[2] CTIA Certification Test Plan for Mobile Station Over the Air Performance, Rev. 3.1, (January 2011).

[3] LightSquared, Ex Parte Notification, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (October 6, 2011).

[4] Letter from Lawrence E. Strickling, NTIA, to Julius Genachowski, Chairman, FCC (February 14, 2012).

[5] Rappaport, T. D., Wireless Communications and Practice (2 Ed.), Prentice Hall, 2002.

[6] Parsons, J. D. The Mobile Radio Propagation Channel (2. Ed.), John Wiley and Sons, Chichester, UK, 2000.

[7] LightSquared, Reply Comments, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (August 15, 2011).

[8] Garmin International, Inc., Comments, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (August 1, 2011).

[9] Javad, "GPS C/N0 variations" (March 15, 2012) *available at* http://www.javad.com/jgnss/javad/news/pr20120315.html.

[10] Kaplan, E. D. and Hegarty, C., Understanding GPS Principles and Applications (2 Ed.), Artech House, 2006.

[11] 3rd Generation Partnership Project, Technical Specification 34.171, V9.3.0 (September 2009).

[12] ISO/IEC 17025:2005, "General requirements for the competence of testing and calibration laboratories."

[13] IEEE 1900.2:2008, "IEEE Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems."

[14] RTCA/DO-229D, Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment (December 13, 2006).

[15] RTCA/DO-235B, Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band (March 13, 2008).

[16] RTCA/DO-327, Assessment of the LightSquared Ancillary Terrestrial Component Radio Frequency Interference Impact on GNSS L1 Band Airborne Receiver Operations (June 3, 2011).

[17] Working Group, Final Report, IB Docket No. 11-109 (June 30, 2011).

[18] Telecommunications Industry Association, TIA Standard Recommended Minimum Performance Specification for TIA/EIA/IS-801-1 Spread Spectrum Mobile Stations, TIA-916 (April 2002).

[19] 3rd Generation Partnership Project, Technical Specification 36.101, V9.10.0 (March 2010).

[20] Letter from Jeffrey Carlisle, Executive Vice President Regulatory Affairs and Public Policy, LightSquared, Inc. to Julius Knapp, Chief, Office of Engineering and Technology, FCC, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (December 7, 2011).

[21] Letter from Jeffrey Carlisle, Executive Vice President Regulatory Affairs and Public Policy, LightSquared, Inc. to Marlene H. Dortch, Secretary, FCC, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (December 12, 2011)
[22] 3rd Generation Partnership Project, Recommended Minimum Performance Specification for Mobile Stations with Position Service, 3GPP2 C.S0036-0 Version 2.0, Section 2.1.1.1.2 (January 29, 2010).

# ATTACHMENT A-1

## NPEF'S CONCERNS ABOUT POTENTIAL OVERLOAD FROM LIGHTSQUARED USER DEVICES ARE UNFOUNDED

NTIA also cites the NPEF testing as evidence that some personal/general navigation devices were susceptible to LightSquared handset signal in the 1627.5-1637.5 MHz band and, as a result it concludes that additional analysis is needed to assess potential impact.[1]

NTIA overlooks the extent to which NPEF's testing and analysis contain a number of material flaws. These include many of the flaws that apply to the downlink tests, such as the biased selection of devices and the failure to control the tests and report all the data, as well as some that are unique to the uplink tests, including failing to report an entire data set for one of the uplink tests. Similarly, the analysis contains many of the same kinds of errors, including the use of an unsubstantiated assumption that -10 dBm of LightSquared uplink signals could be present at the GPS receiver.[2]

As described further below, when these flaws are corrected, it is apparent that there is no risk of overload to a GPS device at either the standoff distance of 4.5 meters that was used in developing the agreement with the US GPS Industry Council regarding Out-of-Band Emissions into the GPS band[3] or even at a distance of 1 meter.

A LightSquared device can transmit an EIRP of up to 23 dBm. This is not necessarily the adjacent band power at the antenna connector of the GPS receiver – the parameter that determines compatibility. The difference between 23 dBm and the power at the GPS receiver input depends on the following:

1. Pathloss
   At a standoff distance of 4.5 meters, there is a free space loss of 49.7 dB. If a more conservative 1 meter standoff distance is used, the loss would be 36.7 dB.

2. Number of transmitters
   For the purpose of this analysis, the number of simultaneously-on transmitters within 4.5 meters is assumed to be 2 as a representative number. For 1 meter, a single transmitter is assumed. Note that this is not the number of devices that have open sessions but the

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[1] Letter from Lawrence E. Strickling, NTIA, to Julius Genachowski, Chairman, FCC, at 5 note 26 (February 14, 2012) ("NTIA Letter" [4]). *See also* National Space-Based Positioning, Navigation, and Timing Systems Engineering Forum (NPEF), Follow –on Assessment of LightSquared Ancillary Terrestrial Component Effects on GPS Receivers, at 36 (January 26, 2012) ("NPEF Report" [1])

[2] NPEF Report [1],at Sections 5.1.1.3 and 5.1.1.4.

[3] *See* Dr. A.J. Van Dierendonck, AJ Systems for the US GPS Industry Council, and Dr. Peter D. Karabinis, VP & Chief Technical Officer Mobile Satellite Ventures, LP, "Interference Analysis of Out-of-Band-Emissions (OOBE) Limits to GPS from Ancillary Terrestrial Mobile Satellite Services in the L-Band," at 5 (August 8, 2002), attached as an enclosure to the Letter from Raul R. Rodriquez, Counsel for the U.S. GPS Industry Council, and Peter D. Karabinis, Mobile Satellite Ventures L.P., to James Vorhies, NTIA (August 8, 2002), which is attached hereto.

number of devices that are *simultaneously on the air* at any instant. Each additional transmitter causes the power to increase by 3 dB.

3. Antenna coupling loss
The dB-averaged antenna gain of cellular devices, averaged over all directions, is typically -4dBi. The typical gain of GPS antennas at low elevation angles, with the peak gain point towards the zenith, is -2 dBi. This would yield a typical antenna coupling loss of 6 dB. The TWG cellular subgroup reviewed the antenna patterns of several GPS antennas and decided to book an antenna coupling loss of 5 dB relative to isotropic antennas on both the LightSquared device and the GPS receiver. The same value of 5 dB coupling loss is used here.

4. Uplink Power Control
LTE uses uplink power control. The maximum power is typically emitted by the UE only at the edge of cell. Assuming that the GPS receiver is outdoors, the transmit power will be reduced by the building penetration loss. LightSquared's LTE link budgets use a building penetration loss value of 15 dB for suburban environments. Therefore, value of 15 dB could be booked as the median value of power control when the UE is outdoors. However, the power control also has to contend with slow fading, which could increase the pathloss and increase the device power in some locations. A reduced value of 10 dB is therefore assumed for power backoff.

5. Duty Cycle of each transmitter
In packet data protocol such as LTE, a given user is almost never given continuous use of the uplink channel. Typical duty cycles are of the order of 16%. A duty cycle of 16% causes an 8 dB reduction of power.

The above factors cause the antenna power at the GPS receiver input to be reduced as shown in Table A-1.1 below, where the progressive contribution of each line item is shown. The frequency is 1632.5 MHz, the center frequency of the lower 10 MHz uplink ATC channel.

**Table A-1.1 Uplink Power from LightSquared UE**

| **Standoff distance (m)** | **1** | **4.5** | **Comment** |
|---|---|---|---|
| **Device EIRP (dBm)** | 23 | 23 | Standardized by 3GPP for LTE |
| **Pathloss (dB)** | 36.7 | 49.7 | Free space |
| Rx. Power (dBm) | -13.7 | -26.7 | |
| | | | |
| **No. of simultaneously on devices** | 1 | 2 | Assumption |
| Power gain/loss (dB) | 0 | 3 | |
| Rx. Power (dBm) | -13.7 | -23.7 | *This is the power that would be received if the uplink channel were a broadcast channel transmitting at maximum power, continuously, with none of the losses shown below.* |
| | | | |
| **Antenna Coupling Loss (dB)** | -5 | -5 | Assumption by TWG Cellular Group |
| Rx. Power (dBm) | -18.7 | -28.7 | |
| | | | |
| **Uplink Power Control** | 10.0 | 10.0 | Based on building penetration loss assumed in LightSquared link budget. |
| Rx. Power (dBm) | -28.7 | -38.7 | |
| | | | |
| **Duty cycle (%)** | 16 | 16 | Assumption: Typical LTE uplink Scheduler characteristics |
| Power reduction | -8 | -8 | |
| Rx. Power (dBm) | -36.7 | -46.7 | |

Based on this analysis, it is reasonable to conclude that the power at the GPS receiver input will be around -37 dBm when LightSquared devices are within one meter of a GPS receiver, and -47 dBm when there are two LightSquared devices within 4.5 meters. None of these levels would cause any of the GPS receivers tested by the NPEF to suffer even 1 dB $C/N_0$ degradation.

This conclusion is based on Test Events 3, 12 and 4, 13. In these tests, the uplink ATC channels were the only LightSquared signals present. There were other tests in which high power LightSquared signals in both the uplink and downlink bands were present simultaneously. These cases represent unrealistic scenarios, since a strong base station signal implies proximity to the base station, which would cause a much greater UE power reduction (through uplink power control) than assumed above.

August 8, 2002

Mr. James Vorhies
Office of Spectrum Management
National Telecommunications and Information Administration
United States Department of Commerce
14th & Constitution Avenues, NW
Washington, DC 20230

Dear Mr. Vorhies:

As described in the attached documents, the U.S. GPS Council ("Council") and Mobile Satellite Ventures L.P. ("MSV") have agreed on specific out-of-band emissions ("OOBE") limits into the GPS band for the ancillary terrestrial component ("ATC") base stations and terminals that MSV would deploy in connection with its proposed next-generation Mobile Satellite Service system. These OOBE limits have been agreed to by the parties in order to protect devices receiving GPS signals from harmful interference from MSV terminals and ATC base stations.

MSV and the Council jointly submitted to the FCC their agreement. The parties urged the FCC to adopt these OOBE limits in its current rulemaking and licensing proceedings. A copy of their joint filing is attached for your information and review.

In addition to their joint filing, MSV and the Council have also completed an analysis of the potential interference to GPS devices from MSV's ATC base stations and terminals. This analysis, a copy of which is also enclosed, quantifies the interference from MSV's ATC in various GPS scenarios and sets out the technical bases for the OOBE limits the parties have developed to protect GPS receivers. The attached document, dated August 8, 2002, supersedes earlier drafts and more clearly expresses the final views of the parties. The parties disassociate themselves from earlier drafts.

In brief, these limits are -100 dBW/MHz for ATC base stations and initially -90 dBW/MHz for terminals operating in an ATC mode. The limit regarding terminals would be tightened to -95 dBW/MHz within five years from the date MSV service commences. This increase in protection is to account for a greater density of users and the need to protect GPS receivers from the aggregation of interference from multiple sources. MSV's present plans are that all its terminals will themselves include GPS chipsets and process GPS signals.

We urge you to review the technical materials developed by MSV and the Council and to meet with our representatives to discuss these issues. We would welcome an opportunity to present our position to the IRAC and/or individual representatives of agencies with interest in this area. In addition, we also urge you to endorse our proposal for OOBE to protect GPS devices and to communicate your endorsement to the FCC.

Respectfully submitted,

MOBILE SATELLITE VENTURES L.P.

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THE U.S. GPS INDUSTRY COUNCIL

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Enclosures

# Interference Analysis of Out-of-Band Emissions (OOBE) Limits to GPS from Ancillary Terrestrial Mobile Satellite Services in the L-Band (IB Docket No. 01-185) August 8, 2002

**Dr. A. J. Van Dierendonck**
**AJ Systems for the US GPS Industry Council**

**Dr. Peter D. Karabinis**
**VP & Chief Technical Officer**
**Mobile Satellite Ventures, LP**

## 1. INTRODUCTION AND EXECUTIVE SUMMARY

Mobile Satellite Ventures, LP (MSV) is proposing to deploy ancillary terrestrial wireless services in the L-band that is currently allocated to Mobile Satellite Services (MSS).[1] At L-band, the frequency range 1525-1559 MHz is assigned to the mobile satellite downlink and the frequency range 1626.5-1660.5 is assigned to the mobile satellite uplink. MSV's use of the L-band brackets the frequency band where GPS is currently operating. MSV proposes an augmented service, via an Ancillary Terrestrial Component (ATC),[2] which includes terrestrial wireless transmissions to overcome satellite signal blockage in densely populated areas. MSV's mobile terminals in ATC mode will receive in the band 1525 to 1559 MHz and transmit in the band 1626.5 to 1660.5 MHz. This means that MSV's ATC base stations (BTSs) will receive in the band from 1626.5 to 1660.5 MHz, and transmit in the band from 1525 to 1559 MHz. Thus, MSV's ATC operations will produce terrestrial transmissions on both sides of the GPS band, potentially generating out-of-band emissions (OOBE) into the GPS band.

MSV and the US GPS Industry Council have conducted technical analyses and have reached agreement on mutually acceptable OOBE limits for MSV's base stations and terminal equipment operating in ATC and satellite mode. The agreed upon broad-band OOBE limits to protect GPS are:

1) **For MSV's ATC base stations:** -100 dBW/MHz over the entire GNSS band (from 1559 MHz to 1610 MHz) and,

2a) **For MSV's terminal equipment operating in ATC mode:** Initially -90 dBW/MHz from 1559 MHz to 1605 MHz, improving to -95 dBW/MHz from 1559 MHz to 1605 MHz for equipment that is placed in service five years following the start of MSV's commercial operations.

2b) **For MSV's terminal equipment operating in satellite mode:** Initially -75 dBW/MHz from 1559 MHz to 1605 MHz, improving to -80 dBW/MHz from 1559 MHz to 1605 MHz for equipment that is placed in service five years following the start of MSV's commercial operations.

The agreed upon limit for narrow-band OOBE of bandwidth less than or equal to 1000 Hz, is 10 dB lower in numerical value than the corresponding broad-band OOBE limit. For example, the narrow-band OOBE limit for MSV's ATC base station is -110 dBW.

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[1] *In the Matter of Flexibility for Delivery of Communications by Mobile Satellite Service Providers in the 2 GHz, the L-Band, and 1.6/2.4 GHz Band,* IB Docket No. 01-185 (Aug. 17, 2001).

[2] *MSV's Next Generation Satellite System Coordination and Interference Considerations,* MSV Presentation to the US GPS Industry Council (May 21, 2002).

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## 2. EMISSION LEVEL DISCUSSION

Un-augmented MSS[3] OOBE into the GPS bands defined the first interference limit to be negotiated for specific MSS entrants. This limit was negotiated at a level of -70 dBW/MHz, developed for a specific aviation application scenario only, and based on a single MSS MET located below the fuselage of an aircraft within 100 feet.[4] Today, this original interference limit is far too excessive for the evolved user base of millions of GPS receivers, the majority of which are mobile, and will be in close proximity to an emitter. In the case of un-augmented MSS, the number of mobile emitters is considered relatively small and far enough away from GPS receivers used for aviation safety-critical operations, such as landing an aircraft. This, of course, is not the case for MSS augmented by ancillary terrestrial operations. Both base stations and mobile terminals can be large in number and, often, in close proximity to GPS receivers, some of which would be used for safety-critical operations. Thus, it is very important to control the emission levels from these terminals and base stations in the GPS frequency band.

Another very important issue regarding OOBE levels in the GPS band is that the interference allotment -70 dBW/MHz is already assigned to the original un-augmented MSS. The proposed ATC augmentation to MSS is an additional, and denser, service. Thus, this new augmented MSS cannot have the same interference allotment in the emissions level originally allocated to un-augmented MSS only.

It is clear that the OOBE limits of any new service that uses spectrum in close proximity to GPS must be set significantly lower than the -70 dBW/MHz level. At the same time, it is understood that MSV must have a stable target for the development and operation of its system (including ATC), which requires the OOBE limits to be sufficient to protect GPS over the long term. The limits agreed to by MSV and the US GPS Council meet this requirement.

The original un-augmented MSS METs could only transmit terrestrially over the return L-band frequencies (from 1626.5 to 1660.5 MHz). MSV proposes ATC operations that would transmit terrestrially in both the forward and return L-band. Thus, the ATC operations' OOBE is coming from both of the adjacent (to GPS) bands, and each band's interference allotment should be allocated separately. Since ATC is in addition to un-augmented MSS, the allocated emissions level for each ATC band would have to be lower than the -70 dBW/MHz allocated to the original un-augmented MSS.

## 3. SCENARIO AND LINK BUDGET DEVELOPMENT

In the MSV proposed system, there are three types of emitters – the BTS base stations, the pico base stations and the mobile earth terminals (METs). The BTSs are expected to be located on top of towers, or buildings, nominally 30 meters above the ground. The pico base stations are essentially repeaters for use in areas of degraded line-of-sight from the BTSs and indoors. Of

[3] The term un-augmented refers to MSS without ATC. The term augmented refers to MSS with ATC.

[4] ITU-R M.1477 at Annex 5. NOTE 1 to ITU-R M.1477: "This Recommendation is not intended to be used to form the basis for future modifications to maximum unwanted emission levels for the band 1559-1610 MHz that are stated in the Annexes to Recommendation ITU-R. M.1343. The maximum unwanted emission levels for the band 1559-1510 MHz stated in Recommendation ITU-R. M.1343 have been developed pursuant to a specific interference scenario, and are not intended to be applied to any service other than MSS MESs operating in the 1-3 GHz range without further study.

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course, the METs are anywhere a user could be. The level of interference to a GPS user is then based upon the distance between the emitters and the GPS user, their respective antenna patterns and polarizations, GPS receiver sensitivity and the emission levels. Reasonable scenarios are presented. First, let us discuss GPS receiver sensitivity.[5]

## GPS Receiver Sensitivity

MSV originally suggested that the legacy -70 dBW/MHz OOBE limit may be good enough to protect GPS from the OOBE of MSV's proposed ATC. However, the original standards, for aviation receivers,[6] were established considering a single, un-augmented MSS MET with an OOBE level of -70 dBW/MHz. Other than the standard safety-of-life margin, there is no margin remaining for any additional interference sources. Legacy GPS receivers are already in existence and will be used on airlines for the next 20 years with no retrofit. In the presence of interference defined by the established receiver susceptibility masks, GPS receivers will not acquire or will lose lock.

In addition, the FCC mobile E911 mandate has driven GPS receiver technology to include enhanced sensitivity. These GPS-enabled E911 cellular telephones are required to track attenuated GPS signals that are at -180 dBW or less, over 40 dB below the thermal noise floor in a 2 MHz band.

## GPS Aviation Receiver Sensitivity and Link Budget

For aviation receivers, values accepted by RTCA and ICAO are -140.5 dBW/MHz for tracking, and -146.5 dBW/MHz for initial acquisition.[7] Well-established link budgets, including a safety margin, equate those numbers to a single -70 dBW/MHz emissions source at distances of 100 feet and 200 feet, respectively, depending upon phase of flight. The 100 feet distance relates to a minimum distance above a source at a Category I decision height. Table 1 provides the link budget for this scenario developed by RTCA for a new version of DO-235 (DO-235A).[8] Note that this link budget is for a single MSS emissions source, and thus, would not include ATC emitters. For the original un-augmented MSS METs, for which the budget was established, this was justified because the density of satellite terminals would be low.

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[5] GPS receiver sensitivity is defined in terms of receiver susceptibility with standard (non-adaptive) gain antennas and not defined in terms of receiver desensitization. The ability to reduce GPS receiver sensitivity towards broadband interference requires elaborate antenna technology, using antenna arrays, making the approach not feasible for the installed base, especially for the mobile user. In addition, attempting to reduce GPS receiver sensitivity toward broadband interference may result in reduced sensitivity of the GPS receiver to the GPS satellite signals.

[6] ITU-R M.1477 at Annex 1. Standards for GPS receivers, developed for aviation, and extended to commercial receivers, including land, marine, and codeless, were established internationally.

[7] *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*, RTCA DO-229C, Appendix C (November, 2001) and *Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment*, RTCA DO-253, Appendix D (January, 2000).

[8] *Assessment of Radio Frequency Interference Relevant to the GNSS*, RTCA DO-235A Draft, Chapter 2 (Current Issue).

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**Table 1 GPS Aviation Category I RFI Scenario Link Budget (Not including ATC Emitters)**

| | | |
|---|---|---|
| | GPS $L_1$ Frequency | 1,575.42 MHz |
| 1 | Emissions mask; spurious out-of-band Broadband Noise | -70.0 dBW/MHz |
| 2 | GPS antenna gain | -10.0 dBi |
| 3 | 100 ft separation distance propagation loss | -66.1dB |
| 4 | RFI at GPS receiver | -146.1 dBW/MHz |
| 5 | Aeronautical Safety Margin | 5.6 dB |
| 6 | Receiver Susceptibility Mask | -140.5 dBW/MHz |

The draft DO-235A also states "An important, and in retrospect, unfortunate aspect of the link budget in Table 1 is that the entire amount of allowable RFI at the receiver is permitted to be consumed by a single MSS MET. As a result, emissions by other RFI sources must be restricted to a greater extent than the original un-augmented MSS METs. The condition that only one MSS MET is always present was a compromise between the MSS and Aeronautical communities. The MSS community wanted to assign probabilities for the presence of one or more METs. The consensus number was that one and only one MSS MET could be present with probability one. Consequently, scenarios involving potential new emitters (RF lighting, public safety devices, UWB devices, etc.) must assume that an MET is present." Consequently, a new aeronautical link budget for new emitters was developed, resulting in a new broadband noise emissions level set at -90 dBW/MHz. This level also accounts for the fact that there could be multiple emitters, such as ATC terminals, in the area.

The link budget of Table 1 can also be applied to ATC base stations and MSV terminals operating in ATC mode with certain adjustments, as discussed below.[9]

**Terrestrial GPS Receiver Sensitivity and Link Budget**

There are essentially three types of terrestrial GPS receiver technologies that have to be considered. The first would be the standard receiver with sensitivity similar to that of the aviation receiver (-140.5 dBW/MHz). The second would be the high precision class of receiver that uses codeless tracking technologies to track the L2 GPS signal, in addition to the L1 GPS signal. Generally, at the L1 frequency, they have a similar sensitivity as the standard receivers. The third type deviates from this, however. That type is the type designed to operate indoors and outdoors under heavy foliage. Receivers embedded in E911 cellular terminals are in this category. This enhanced GPS receiver technology is expected to migrate throughout the installed user base.

Table 2 is the proposed ATC terminal link budget. The scenarios described in Table 2 are applicable to the MSV terminals operating in ATC mode. This link budget starts with a receiver sensitivity to broadband interference (-144.5 dBW/MHz) that is typical for the GPS technology used in E911 cellular terminals, and is 4 dB lower than for the more robust aviation GPS receivers given in Table 1. This is to insure that the interference doesn't dominate the thermal noise floor for which those receivers were designed to operate indoors and under heavy foliage.

[9] MSV terminal equipment, when completing a link through the MSS satellite, will operate initially at a -75 dBW/MHz OOBE limit. Five years following the start of MSV's commercial operations, the OOBE limit for MSV terminal equipment when completing a link through an MSS satellite will improve to -80dBW/MHz.

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For the E911 scenario in this environment, it is assumed that a single ATC terminal is 4.5 meters (15 feet) away from the E911 terminal. This link budget results in an OOBE EIRP of -95 dBW/MHz.

**Table 2. ATC Terminal Scenario Link Budget**

| Parameter | Value |
|---|---|
| GPS Receiver Interference Susceptibility (dBW/MHz) (Broadband Noise) | -144.5 |
| Propagation Loss (dB) (Minimum Distance Separation (m)) | 49.5 (4.5 m) |
| GPS Receive Antenna Gain (dBi) | 0 |
| Maximum Allowable OOBE EIRP (dBW/MHz) | -95 |

**BTS/ATC Scenarios**

With respect to the BTSs and pico stations, as defined in MSV documentation, their location has to be coordinated to prevent interference to nearby GPS timing receivers. It is recognized that timing receivers used for synchronization of networks, such as cellular networks, would usually be located at elevated levels, such as on top of buildings. Thus, they could be located at the same level as the BTS antennas located on the towers, or could be located near pico station antennas, and therefore subject to the high-gain part of the BTS antenna patterns. With respect to the airborne GPS user, BTS towers should not be a problem. Towers will not be allowed near the path of an aircraft, and the BTS antenna pattern, which is tilted toward the ground, will help prevent interference to the GPS receiver on an aircraft.

GPS timing receivers have become the de facto standard for creating precise timing synchronization for virtually all digital cellular systems today. In addition, most of the internet transmissions for terrestrial and satellite reception are also synchronized to GPS time, which is in turn synchronized to the atomic clocks on board the GPS satellites. The resulting timing errors in cellular networks is less than 50 nanoseconds as defined by earth based atomic clocks, to which the GPS satellite clocks are referenced.

GPS timing receivers track at least 5 satellites in order to deliver this level of accuracy. GPS timing receivers are typically located on rooftops of buildings or on the masts of cell sites (tens of thousands such units have been so installed worldwide.) Some receivers are also located indoors in equipment racks that also hold servers and other computer-related products. Also, since many GPS timing receivers are located on masts atop buildings, there is a high likelihood that MSV base station transmitters could be either co-located or located at approximately the same elevation above ground. Thus, the potential of interference to timing GPS from MSV's ATC base stations and MSV's ATC mobile terminals was a concern that has been addressed by the agreed upon emissions limits stated at the outset of this report.

The ATC pico stations represent another potential source of interference. It has been indicated by MSV that pico base stations may be located on ceilings of buildings or on building walls, using omni-directional transmitting antennas. To substantially reduce the potential of

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interference to GPS from any ATC base station deployment, MSV has agreed to the much-improved OOBE limit of -100 dBW/MHz.

The MSV terminals operating in ATC mode may potentially cause the largest interference problem to GPS users. MSV has agreed that their terminals will initially emit OOBE at or below the -90 dBW/MHz level in the GPS band and has also agreed to implement an improved OOBE limit of -95 dBW/MHz for MSV terminals operating in ATC mode commencing five years after the introduction of their service. The scenarios for the MSV terminals operating in ATC mode are presented in Table 2. These limits will be met by MSV terminals over the frequency range from 1559 to 1605 MHz.

## MSV Terminals and Base/Pico Station Scenarios and Link Budgets

As discussed above, since un-augmented, space-based MSS MET and UWB have already received emission level allocations, and the fact that MSV terminals operating in ATC mode will be in the same area, the agreed emission level for base and pico stations in the scenario is -100 dBW/MHz. Thus, their emissions will be somewhat less than the emissions of MSV terminals operating in ATC mode, allowing these terminals to emit at the higher -90 or -95 dBW/MHz level. This is appropriate since these stations can implement larger filters with more out-of-band insertion loss.

This is not the limiting scenario for the MSV terminals operating in ATC mode. Modified scenarios and link budgets equivalent to the ones given in Table 2 are the limiting scenarios and link budgets. The modification starts by assigning the same receiver susceptibility mask two additional emitters – a base/pico station and a terminal. In these close-in scenarios, only one emitter, the MSV terminal operating in ATC mode, should be considered. It is assumed here that the base/pico station will be emitting at 5 to 10 dB lower power.

## Link Budget Modifications for Narrowband Emissions

Since the GPS C/A code repeats at a 1 kHz rate, the signal spectrum is a line spectrum with varying line magnitude, and is thus more susceptible to narrowband emissions at certain frequency offsets from 1575.42 MHz (depends upon PRN code). This susceptibility varies by approximately 10 dB versus emission bandwidth for bandwidths under 100 kHz. This varying GPS receiver susceptibility is indicated in the RTCA WAAS and LAAS MOPS, and is summarized below in Figure 1. The wider the emission bandwidth, the more spectral lines are affected, and the effect is averaged over the spectral lines. It should be emphasized, however, that it is the OOBE bandwidth, not the BTS, pico station, or terminal signal bandwidth that is relevant. For example, an emitted local oscillator spur would be classified as a narrowband emission, yet transmitter noise would be classified as a wideband emission. Inter-modulation products, if there are any, would have bandwidths similar to the signal bandwidth. Inter-modulation products are not expected to occur in MSV implementations

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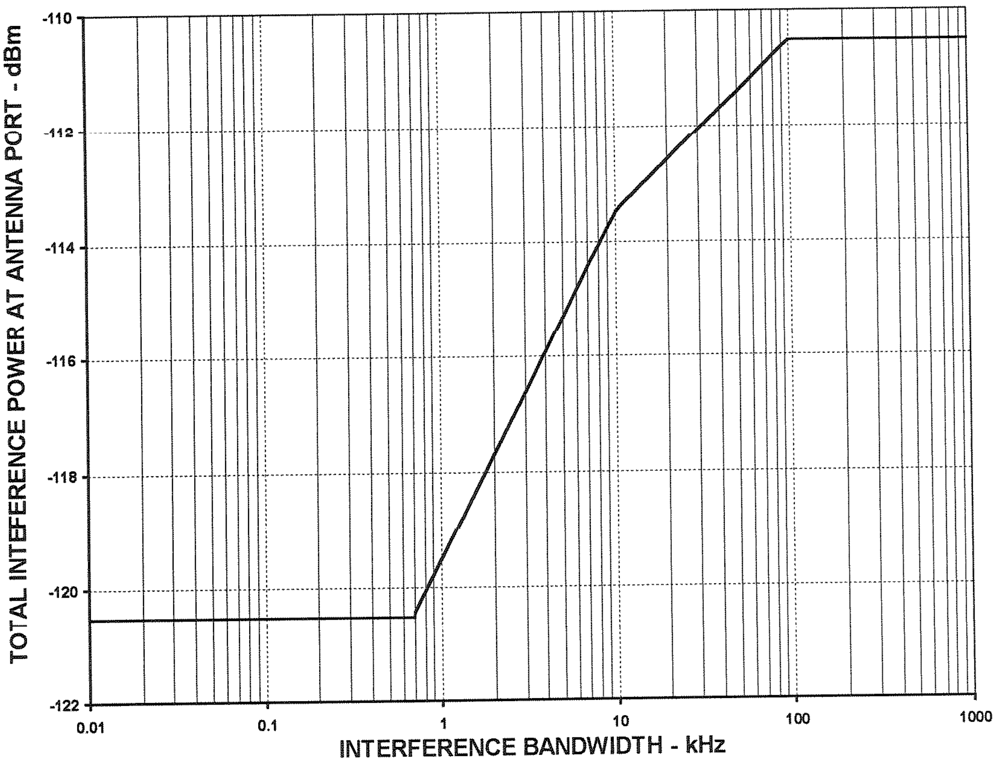


**Figure 1. GPS Receiver Susceptibility Versus Interference Bandwidth**

**Frequency Band Protection**

The GPS frequency band is 1575.42 MHz ±12 MHz, and accurate GPS receivers take advantage of as much bandwidth as possible. That is how accurate GPS C/A code receivers mitigate multipath – they track the sharp edges of the code transitions. Essentially, they are tracking the outer lobes of the C/A code spectrum. Thus, the entire GPS band must be protected at the indicated emission levels. Furthermore, the GPS military signals cover the entire 24-MHz band. As the GPS services and its augmentations evolve, more frequency bandwidth will be used. Consequently, these OOBE limits protect the evolving GPS service in the range from 1559 MHz to 1605 MHz.

## 4. SUMMARY & CONCLUSION

Base station/pico base station transmitters of MSV's ATC network will comply with the -100 dBW/MHz OOBE limit, taking into account their antenna pattern. OOBE from MSV terminals operating in ATC mode will initially be limited to -90 dBW/MHz, and will improve to -95 dBW/MHz, for new ATC terminals, in five years from service commencement. MSV's present plans are to incorporate GPS chips and signal processing in its terminals. The agreement reached by MSV and the US GPS Industry Council regarding OOBE limits for MSV's ATC operations is appropriate for the protection of present and future GPS operations and provides a stable environment for the development and operation of MSV's proposed system.

# DECLARATION OF STEVE HOLLEY

I, Steve Holley, make the following declaration.

1. I was employed as a Principal Engineer at LightSquared Subsidiary LLC from March 12, 2007 to March 2, 2012.

2. In my role as Principal Engineer, I participated in the NPEF's "General Location/Navigation" device testing from October 25, 2011 to November 3, 2011, where I observed the test processes, test-set up, and test events.

3. My observations of the testing included the following:

    a. Test participants oriented test device antennas as they chose, apparently to provide maximum exposure to LightSquared's LTE signal, rather than putting them flat on the test table.

    b. Test participants modified test devices between tests, including changing test device antennas. The nature of these modifications did not appear to be recorded.

    c. On the second day of testing, the duration GPS baseline time of several tests was significantly shortened from the established test event durations.

    d. During one test event, the Test Director entered the testing area before the completion of the test. Participants were instructed to remove the last few minutes of collected data.

    e. Each test participant was assigned a grid point location but was free to work within its assigned area. Efforts were made by participants and test administrators to ensure proper spacing of test devices, however, due to the number of devices involved, the spacing between devices varied. These variances in distances between test devices did not appear to be recorded.

    f. Test administrators performed "sniff tests" before the testing program started to determine if the devices were transmitting, however the "sniff test" was not performed before each test cycle.

    g. No testing was performed to determine whether devices were "coupling."

    h. Raw data was not generated in one single format. Because the data of government participants was proprietary, it was not possible to review all data for consistency.

    i. Although test participants were supposed to provide data at the end of each day to the Test Director in standard NEMA format, some manufacturers were permitted to provide their data later, supposedly to download data from their devices or convert the data to NEMA format.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on March 15, 2012.

Steve Holley

## EXHIBIT B

## ANY CONCLUSION REGARDING THE COMPATIBILITY OF AVIATION GPS RECEIVERS IS PREMATURE

NTIA's handling of the Aviation case is another example of its reaching conclusions without engaging or considering potential solutions offered by LightSquared. The FAA report on which NTIA relies reached a conclusion that mitigation is impractical for low-altitude cases before the FAA had fully defined its criteria, including the establishment of an appropriate propagation model for low altitudes and the definition of compatibility criteria (including exclusion zones) to be used to evaluate low altitude applications,[1] or met with LightSquared to discuss a proposal to accommodate the FAA's concerns.[2] The FAA Report purports to reject the LightSquared low-altitude mitigation proposal because it is impractical, a view that NTIA endorses without explanation, but such a view is clearly premature without the FAA first clearly defining its evaluation criteria and engaging LightSquared on the appropriate propagation models and the specifics of LightSquared's willingness to modify its network to accommodate the FAA's stated concerns. As the FAA has acknowledged, its technical analysis is incomplete, and it has not fully evaluated LightSquared's proposed solution to address all articulated FAA concerns regarding low altitude navigation applications of GPS.[3] Key elements of the FAA's analysis have not been based on substantial evidence or submitted to technical review. Thus, any conclusion that LightSquared's proposed operations would be incompatible with aviation GPS receivers is premature.

The vast majority of joint FAA and LightSquared work was performed and time spent on the higher altitude cases, where the "FAA concluded that the compatibility situation improves as the aircraft altitude increases so that at higher altitudes the interference is expected to be acceptable;"[4] only a very short time in the final few weeks of the process (a process the FAA abruptly terminated) was spent evaluating the low altitude cases, which now form the basis of NTIA's objections.

Throughout the process, the FAA failed to clearly and consistently identify its evaluation criteria for aviation applications of GPS, especially as they relate to low-altitude applications, and failed to provide any evaluation criteria for GPS uses for which mandatory GPS-related standards do not exist, leaving open the question of what other criteria may apply. The FAA initially failed to identify Terrain Awareness and Warning System ("TAWS") as a unique scenario to be analyzed in the RTCA report, and then once it did so, provided ambiguous information as to whether a minimal exclusion zone would be acceptable and failed to define

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1 For purposes of this Exhibit, the terms "criteria" generally refers to the methodologies proposed by the FAA to evaluate LightSquared's proposed operations and mitigations, as well as criteria proposed by the FAA to evaluate whether the proposed operations would impact aviation uses of GPS.

2 FAA Status Report: Assessment Of Compatibility Of Planned Lightsquared Ancillary Terrestrial Component Transmissions in the 1526-1536 MHz Band with Certified Aviation GPS Receivers, at Section 6 (Jan. 26, 2012) ("FAA Report" [1]).

3 FAA Report [1], at Sections 4 and 6.

4 Letter from Lawrence Strickling, Administrator, National Telecommunications and Information Administration, to Julius Genachowski, Chairman, Federal Communications Commission, at 5 (Feb. 14, 2012) ("NTIA Letter" [2]).

evaluation criteria for the "residual operational risks" of GPS at low altitudes included in the FAA Report, and introducing new and ambiguous concerns like impacts of inadvertent handset use on aircraft,[5] making it impossible for LightSquared to even evaluate, let alone respond to, the potential concern. The FAA provided several different propagation models during the process to evaluate LightSquared's system without clearly settling on any given one until the final FAA Report, and even that model is severely flawed, as discussed below. Moreover the FAA focused improperly on outdated proposals that are no longer relevant and failed to consider available mechanisms to ensure that LightSquared's system operates in compliance with the FAA's stated criteria.

In contrast, LightSquared has submitted a declaration from a distinguished expert in the field of wireless propagation, Dr. John David Parsons, and from a distinguished TAWS expert John Howard Glover, both showing that key aspects of the FAA's report's analysis are not supportable.[6] For example:

- The FAA provided arbitrary or no criteria to derive breakpoints, without any physical justification. Given that *a priori* knowledge of the blocked/unblocked status of base station antennas is necessary in the FAA model, the LightSquared model, also utilizing this information, is closer to physical reality and is supported by the MSS propagation literature.

- The FAA failed to take into consideration the operational realities of TAWS equipment in use, which are more robust and use a sloped approach, rather than the stepped approach for minimum required terrain clearances ("RTC") near airports. Nor did the FAA take into account the many redundancies in TAWS equipment, including alerts well above the minimum RTCs, alternate position sources, and alerts aircraft receive in the event of a possible loss of GPS – the likelihood of which was never established.

An objective examination of LightSquared's mitigation proposals – and the underlying technical analysis – supports LightSquared's view that compatibility can be established between LightSquared's operations and the FAA's stated criteria – even assuming the most conservative definitions of those criteria and without requiring changes to existing FAA standards, as currently articulated. LightSquared made every effort to address the FAA's concerns by proposing to limit its "power-in-air" to the coverage defined in the FAA's Report. Outside of these exclusion zones, LightSquared's aggregate ATCt signal would never exceed -34.1 dBm.[7] LightSquared has presented evidence that its proposal is practicable and effective. It has run models and analysis, described in more detail below, based on actual GPS-based approach and departure procedures at Ronald Reagan Washington National Airport ("DCA") and has completed TAWS analysis demonstrating compatibility. LightSquared continues to believe that

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[5] FAA Report [1], at 16 (stating that the TAWS and HTAWS exclusion zones would need to be coordinated with industry and that "the FAA has not made operational and safety assessments for the additional areas of consideration identified in Appendix A Section 6 "Residual Operational Risks" and these risks have not been coordinated with the users who would be impacted.") *See also* FAA Report [1], at 71.

[6] Attached to this Exhibit are the prior declarations and new declarations from Dr. Parsons and Howard Glover reaffirming their views and responding to the FAA Report. See Attachments B-1, B-3, and B-4.

[7] This limit was agreed to jointly between the FAA and LightSquared based on an assessment of existing minimum operating standards, which include an extra safety margin of 6 dB.

it can develop, deploy, and monitor its system so as to address all FAA concerns, including through the use of appropriate independent third parties to monitor compliance.

LightSquared previously provided a detailed assessment of these issues in Appendix C to the FAA Report, which is incorporated herein by reference. Given the extremely short timeframe that LightSquared was afforded to review the draft FAA Report, LightSquared offers additional critiques of the FAA's proposed model below. There are several other issues with the FAA Report. These are not re-discussed here but cataloged in Appendix C of the FAA Report. NTIA adopted the FAA's Report without any discussion of LightSquared's views in Appendix C.

Even if a comprehensive analysis was to show some incompatibility, the FAA has presented no evidence of its conclusion that it is impractical to conduct a more comprehensive testing program that might show that the standard could be modified without requiring any existing receivers to be retrofitted or replaced. In that regard, the FAA ignored that independent laboratory testing of certified aeronautical GPS receivers has demonstrated sufficient additional resilience to drastically transform the technical analysis in favor of compatibility. Given this evidence, the FAA at a minimum should have developed a robust testing program that would have included testing of a representative sampling of receivers currently in use. But even if receiver modifications were required, neither FAA nor NTIA have presented more than generalized statements, without empirical evidence, that the task would be impracticable.[8]

## I. THE FAA'S ANALYSIS IS FUNDAMENTALLY FLAWED AND LACKS SCIENTIFIC VALIDITY

As an initial matter, the FAA abandoned the technical process prematurely, at a time when key methodologies, assumptions, and criteria were still being evaluated. LightSquared continues to believe that an objective review of LightSquared's underlying scientific analysis and resolution of the few remaining issues[9] between the FAA and LightSquared would demonstrate compatibility between LightSquared's proposed system and uses of FAA certified GPS receivers.

### A. The FAA devoted insufficient time to the key low-altitude cases

The scope of the RTCA Report, commissioned in March 2011 and finalized in June 2011,[10] was to "include receiver vulnerability, as well as [operational] scenario studies including aggregate effects of LightSquared's transmissions on GPS receivers used in aircraft."[11] In conducting its study, the FAA identified five operational scenarios as representative of aviation

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8 Both NTIA and FAA state that it would take 10 or more years to develop new standards and retrofit aircraft with new equipment. NTIA Letter [2], at 7; FAA Report [1], at 71. Neither offered evidence that the task would be impracticable in this instance, especially given that the receivers tested were more robust than existing receiver standards, suggesting that only a small percentage of receivers may actually need to be retrofitted.

9 See FAA Report [1], at C-7.

10 RTCA Report: Assessment of the LightSquared Ancillary Terrestrial Component Radio Frequency Interference Impact on GNSS L1 Band Airborne Receiver Operations, DO-327 (June 3, 2011) ("RTCA Report [3]").

11 RTCA Report [3], at 1.1.4 (citing FAA Letter Request dated March 3, 2011).

uses of GPS,[12] but it did not analyze TAWS applications of GPS and it concluded that all identified lower altitude scenarios below 300' (Cat I, II, and III) are compatible with LightSquared's proposed operations.[13] As a result, the RTCA Report focused on analyzing aggregate impact at higher altitudes above 525 meters[14] and did not analyze TAWS.

It was not until October 2011 that the FAA began shifting the attention of the working group to applications and criteria at lower altitudes, for both navigation and terrain awareness, on which NTIA now bases its objections.[15] LightSquared attempted to engage on this topic immediately, seeking clarification of the FAA's interpretation of its criteria, including its views regarding an appropriate propagation model for low altitudes and the acceptability of possible mitigation efforts by LightSquared. The FAA had not provided this information when it terminated the process at the end of the year.

### B. The FAA has misstated or omitted key facts

Even assuming the FAA had defined or established a scientifically-based methodology and criteria to evaluate LightSquared's system, it failed to consider key facts. First, it ignored evidence that all aviation devices tested performed better than the standards established by the FAA, as documented in the RTCA Report Appendix D and explained more fully in Section E.2, below.

Second, although with LightSquared's proposed modifications no retrofits or "fixes" would be required for certified GPS receivers, no basis exists for the FAA's position that new receiver standards or retrofits – even if required for some receivers– would not be feasible.[16] The FAA's view that new receiver standards and equipment would take more than a decade to implement lacks empirical support. If, for example, a more robust testing program of representative aviation receivers demonstrated that only the standards – not the underlying equipment – needed updating, the timeframe to update the standard and the associated costs

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[12] The RTCA Report evaluated five operational scenarios selected by the FAA, including Cat I, II, III approaches requiring GPS down to 100'. RTCA Report [3], at 3. 1. The RTCA Report did not contain any specific requirements related to TAWS.

[13] RTCA Report [3], at 3.1.2.

[14] RTCA Report [3], at Table 6-4 (showing that the received RFI power spectral density (PSD) is greatest for the FAF WP Case, when the aircraft is 535.2 m height. The value at this height is -73.55 dBm/MHz. )

[15] The FAA Report also suggests the possibility of additional GPS requirement being defined for Visual Flight Rule and Unmanned Aircraft and other operations. For the purpose of this discussion, in light of the fact that FAA has not previously presented these as requirements nor established evaluation criteria, LightSquared is not attempting here to address its compatibility with these uses. LightSquared is also not addressing the FAA's indication for the first time in Section 6 of its Report (Summary and Conclusions) that additional work is needed to examine the potential impact of LightSquared handsets on certified GPS receivers. The Report makes no effort to justify this suggestion and ignores the conclusions in the May RTCA Report that ATCt base stations were the dominant concern.

[16] *See e.g.* FAA Report [1], at Section 6. *See also* NTIA Letter [2], at 7. *See also* Issues Associated with Protecting and Improving our Nation's Aviation Satellite-Based Global Positioning System Infrastructure: Hearing Before the Subcommittee on Aviation of the House Committee on Transportation and Infrastructure, 112th Congress (Feb. 8, 2012) (testimony of John Porcari, Deputy Secretary of Transportation) ("there's no easy retrofit or filter or any other kind of retrofit that would, from a safety-of-flight perspective, make the proposal, as currently proposed by LightSquared, compatible with aviation.").

could be significantly shortened and accomplished in the near term. Likewise, even if testing showed that some receivers needed to be retrofitted, no support exists that the cost or time associated with such retrofitting could not be accomplished in a timely and cost efficient manner. . Receiver standards – indeed most technical standards –evolve regularly and sometimes under compressed time schedules to address specific issues and new advances in technologies, and there is no evidence to suggest otherwise here. In fact NTIA stated that it would request "through the Department of Transportation that the FAA initiate an effort to examine what changes could be made to the existing standard to eventually make certified GPS aviation receivers compatible with a signal in the lower 10 MHz."[17] For example, TSO-C151b applicable to TAWS is currently being revised,[18] providing an opportunity to address concerns in the near term, including updating TAWS certification standards to eliminate outdated requirements to reflect technological advances in TAWS equipment and aircraft operations.

Third, no support exists for the position that aviation devices need to have a "wide-band receiver with a slow rolloff of the frequency response well beyond the allocated GPS band."[19] LightSquared has demonstrated the feasibility of using filters to allow even high-precision receivers to function within the allocated GPS spectrum, without "listening" beyond it.[20] Indeed, the FAA's testing of a limited number of certified aviation GPS receivers demonstrates conclusively that their performance exceeds the FAA's minimum requirements contained in existing certification standards.

### C. The FAA failed to consider TAWS expert's assessment of the flaws in its analysis

In Appendix C to the FAA Report, LightSquared presented the FAA with the assessment of a TAWS expert[21] that temporary loss of GPS information to TAWS equipment in the very low altitude environment would not constitute a significant lowering of the level of flight operational safety, due to both the functionality of modern TAWS equipment, the redundancies built into TAWS, and the inclusion of obstacles in many modern TAWS equipment. LightSquared has provided a declaration from Mr. Glover as Attachment B-4 to further support LightSquared's position. Among the key unrefuted arguments are the following:

- In the process of descending to an altitude low enough for the system to theoretically be exposed to overload-induced loss of GPS data, the airplane must pass through an environment where a TAWS alert will be given before that airplane enters the very low

[17] NTIA Letter [2], at 7.

[18] Draft TSO-C151c – Terrain Awareness and Warning System (Jan. 2012).

[19] Porcari, s*upra* note 16 ("In general terms, the more precise the GPS receiver -- for example, the avionics in an aircraft -- the more precise they are, the more that they are likely to have a wide-band receiver that in fact needs to be able to listen beyond the GPS frequency, acknowledging that and building a policy around that would be, we think, a very good use of staff time and, from a policy perspective, critical to protecting GPS as an asset.")

[20] *See* Exhibit C below.

[21] The expert, Mr. Howard Glover, has worked for more than 35 years on the development, flight testing, and certification of TAWS. His experience includes early Ground Proximity Warning Systems for civil and military aircraft and also modern terrain and obstacle awareness and warning systems and displays. He was secretary of the EUROCAE working group which developed TAWS design standards for US and European certification. He is the holder of more than a dozen patents in the field of airborne alerting systems. He was an FAA Systems and Equipment Designated Engineering Representative for more than 20 years.

altitude zone. In this case it can be assumed that the flight crew will have taken action to avoid the terrain or obstacle threat before the loss of signal has occurred.

- For TAWS equipment that rely on position data from a multi-source navigation computer, the loss of GPS signal does not degrade the position data until Inertial Reference System drift errors become significant – typically only after several minutes. Consequently, Class A TAWS equipment – which are on all commercial aircraft operating under Part 121 operating in an airport terminal airspace environment are relatively immune to a temporary loss of GPS data.

- For TAWS that have internal GPS receivers, they must also have the capability of monitoring the validity and position error of the GPS system, and the TAWS must provide an indication to the pilot if the GPS error is excessive. For these systems the flight crew will be aware that the TAWS system is degraded if a loss of GPS signal occurs.

- TAWS equipment used in commercial aviation have several alerting functions that use radio altimeter signals for determining the height of the airplane above the terrain. These functions are independent of GPS position data.

- Even if a loss of GPS signal occurs while a TAWS alert is in progress, it is unlikely that the pilot would assume that the terrain threat has ceased, and instead the pilot would ensure adequate terrain clearance by immediately climbing to a higher altitude.

### D. The FAA failed to consider LightSquared's technical proposals to limit power-in-the-air and address concerns, instead focusing on unnamed practical difficulties in administering LightSquared's proposal

LightSquared made every effort to address the FAA's concerns by proposing to limit its "power-in-air" to the coverage defined in the FAA's Report. Outside of these exclusion zones LightSquared's aggregate ATCt[22] signal would never exceed -34.1 dBm. This proposal involves significantly powering back its base stations by:

- Restricting the power levels of LightSquared base stations in urban areas to ensure that the aggregate emissions at the worst-case altitude over the largest cities do not exceed the overload threshold established in FAA certification standards for GPS aviation receivers and TAWS equipment;

- Limiting the power levels of all LightSquared base stations so as to protect terrain avoidance systems everywhere beyond the exclusion zones in the FAA Report;[23] and

[22] Consistent with FAA and aviation industry practice, LightSquared refers to its terrestrial operations as ATCt when in the context of aviation discussions. This is done to avoid confusion between this term and the established FAA acronym of ATC which refers to "Air Traffic Control."

[23] FAA Report [1], at Section 1.4.

- Agreeing to further limiting the power levels of LightSquared base stations near airports so as to protect navigation during aircraft takeoffs and landings.

In addition to ignoring LightSquared's proposal for addressing all of the FAA's stated TAWS criteria – at significant operational and monetary cost to LightSquared – the FAA also ignored a high-level method proposed by LightSquared to effectively control power in the air, designed to ensure compatibility for GPS receivers in takeoff and landing phases or to engage in more detailed review and analysis.

**E. The FAA failed to adequately define or support criteria used to evaluate LightSquared's system**

First, as discussed in more detail in Section II below, during the follow-on work to the RTCA Report, the FAA changed several fundamental aspects of the propagation models used for evaluation. Indeed, the FAA continued to change its proposed propagation models – often without justification – throughout the discussions with LightSquared and even after the FAA formally terminated discussions with LightSquared. A more detailed discussion and critique of these models is included in Section II.

Second, as discussed above, the RTCA Report selected and defined operational scenarios that would be representative of aviation uses of certified GPS receivers. Those scenarios included high-altitude scenarios,[24] generic low altitude/terminal area procedures,[25] Category I Precision Approach Procedures[26] used by aircraft on instrument approaches to airport runways, Category II/III Precision Approach Procedures,[27] and Taxiway scenarios.[28] The RTCA Report did not provide evaluation criteria or examine scenarios specific to TAWS, nor did it examine general low altitude navigation applications beyond the Cat I/II/III procedures.[29]

When the FAA first raised low-altitude applications as a potential issue in October 2011, it did not provide specific support for some of its asserted criteria, including the acceptable exclusion zones that could be considered in the TAWS analysis. It also provided new applications of GPS at low altitudes with only limited operational use of certified GPS receivers. Among the undefined and unquantified requirements outlined in the FAA Report are:

While the FAA attempted to define acceptable exclusion zones in Section 1.4 of the FAA Report, that definition varied even during the drafting of the FAA Report and included a caveat that the exclusion zones would need to be coordinated with the industry, suggesting that even the criteria defined in Section 1.4 may be subject to change. For the other low altitude applications

[24] RTCA Report [3], at 3.2.

[25] RTCA Report [3], at 3.3.

[26] RTCA Report [3], at 3.4.

[27] RTCA Report [3], at 3.5.

[28] RTCA Report [3], at 3.6.

[29] RTCA Report [3], at 3.1

of GPS, the FAA did not define criteria that could be used to evaluate LightSquared's system.[30] As discussed herein, although the FAA has not fully defined its criteria or requirements, LightSquared believes that its proposed mitigations will demonstrate compatibility with the criteria articulated in the FAA Report.

### F. Various other elements of the FAA's analysis and criteria are flawed

#### 1. GPS Reference Antenna Pattern

For negative elevation angles, the FAA allowed a difference of 6 dB between the horizontal and vertical polarization responses of the "reference GPS antenna," although all examples of GPS antenna provided by the FAA had a much higher difference – close to 11 dB. LightSquared stated its position in the FAA Report on this subject on page C-34.

LightSquared believes, as stated in documents presented to the FAA in meetings during the study that, based on the example antenna pattern used in the RTCA Report, in which the antenna pattern is based on RTCA/DO-235B, Fig. G-13, a minimum discrimination of 11 dB is appropriate in the elevation angle range of 0 to -30 degrees. It is also noteworthy that the RTCA/DO-235B states, "For horizontal polarized signals in the backlobe region, the data suggest a conservative polarization mismatch loss factor is 15 dB."[31]

A higher discrimination of the horizontally polarized signal reduces the net Radio Frequency Interference ("RFI") power as LightSquared's base station signals are dual polarized with approximately equal power in linear-vertical and linear-horizontal polarizations.

Although not discussed with the FAA owing to the premature termination of discussions, subsequent to those discussions ending, LightSquared has indicated to the NTIA that it is willing to use Left Hand Circular Polarization (LHCP) in its base stations as a potential mitigation measure. It should be noted that the antenna discrimination assumed in the analyses in the FAA Report will not be reduced when the base station polarization is changed from dual, linear cross-polarized to LHCP – if anything, there may be a small amount of additional discrimination owing to a residual amount of cross-polar discrimination between LHCP and RHCP.

#### 2. Measured Performance of Aviation GPS Receivers

The FAA's analysis was based exclusively on the RTCA Minimum Operational Standards ("MOPS") as specified in RTCA/DO-239D, completely ignoring the results of the tests performed on four certified aviation receivers by Zeta Associates, which demonstrated that the resilience of the receivers exceeded these MOPS. Since then, three additional certified aviation receivers have been tested by LightSquared and its partners. The results are shown in Table B.I.1 below.

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[30] FAA Report [1], at 16 ("the FAA has not made operational and safety assessments for the additional areas of consideration identified in Appendix A Section 6 "Residual Operational Risks" and these risks have not been coordinated with the users who would be impacted.")

[31] RTCA/DO 235B, Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band, at G-14 (March 13, 2008) ("RTCA/DO-235B").

**Table B.I.1 Margins of Measured Aviation Receiver relative to the MOPS (dB)**

| | **Lower-10 MHZ ATCt Channel** |
|---|---|
| Zeta Rx-1 | 27 |
| Zeta Rx-2 | 26.4 |
| Zeta Rx-3 | 26.4 |
| Zeta Rx-4 | 23.7 |
| ALU Rx-1 | 13.1 |
| ALU Rx-2 | 18.1 |
| ALU Rx-2 | 18.1 |

### 3. Implication of Channel Fading for Compatibility

The presence of channel fading will cause the RFI Power from each base station to change over time. Section II.C.3 below shows that fast fading comparable to cellular/MSS channels is not feasible in the LightSquared scenario owing to the lack of time-varying local multipath at the GPS receiver. However, slow fading owing to changes in the path geometry (including local multipath reflections around the base station), as the plane traverses its course, *can* exist. It is important to take a high level view of what this means for compatibility.

The FAA has taken a position that every time the RFI power exceeds the threshold level, it comprises a functional failure of the GPS receiver.[32] This is far from the way GPS receivers actually behave. At a fundamental level, in A GPS device's tracking mode, there is a coherent integration time of 20 ms for all navigation functions – 20 ms is the symbol duration of the message channel carried by the GPS L1 C/A code. Beyond this, the integration is continued incoherently over several symbols. Typically, in the tracking mode, the carrier tracking loop bandwidth is less than 10 Hz. Thus, fades of duration less than 100 ms are unlikely to cause perturbation to the GPS receiver. This is yet another reason why fast fading, even if it existed, would be reduced by the effect of averaging within a time period that is substantially longer than the mean fade duration.

The slow fading bandwidth will be morphology-dependent. It is clear from geometrical considerations that, at the lower altitudes, which are what the FAA now identifies as the more critical use cases, the fading bandwidth will be greater than at higher altitudes. Clearly, some reduction of RFI power will occur due to the limited response time of a GPS receiver to a time varying adjacent-band signal..

Furthermore, assuming that each event where the RFI power exceeds the threshold value is statistically independent, the FAA proposes that multiplicative probability rules be applied to

[32] FAA Report [1], at Section 3.2.3.

derive the probability that the RFI power remains continuously below the threshold for a period of 1 hour.[33] This leads to potentially specifying the RFI power requirement at probabilities of 1E-10. The FAA did not insist on a pass/fail metric based on this criterion as it lacked the computing resources to simulate this but has opined that the "rare probability requirement" is a lower bound to the estimate of the received RFI power.[34]

LightSquared believes that this logic is fundamentally flawed for the following reasons:

First, it is questionable whether the lognormal probability distribution assumed for slow fading is an accurate representation of physical reality at the individual event-level probability of 1E-6. The lognormal distribution is used to model measured data in cellular propagation at much higher probability levels than 1E-6. There is no empirical evidence that the lognormal model will continue to hold at P = 1E-6 -- the lognormal model is a mathematical function that has been fitted to experimental data and not derived from physical considerations. In practice, it has been found that the tails of the probability distributions of observed data are shorter than those predicted by their mathematical models.

Second, to assume that the power at P=1E-10 can be predicted by multiplying individual event probabilities, each at P=1E-6, represents a physically meaningless application of probability theory.

Third, ignoring the above misapplications of statistics, it is noteworthy that the P=1E-6 requirement was derived from the requirement of service continuity over a period of 1 hour. In the low altitude applications, both for takeoff/landing and TAWS, the basic use case has a much shorter duration than 1 hour. Hence, only the mean power requirement is relevant in these cases.

## II. THE FAA'S PROPOSED PROPAGATION MODELS USED IN ASSESSING COMPATIBILITY WITH LIGHTSQUARED'S ATC NETWORK ARE FLAWED

This section summarizes the arbitrariness and inconsistencies of the FAA's propagation models. This section is also supported by declarations from wireless industry technical expert, Dr. Parsons, including a critique of the January 13, 2012 draft version of the FAA Report.[35] These declarations are attached as Attachments B-1 and B-3. In addition, Attachment B-2 contains a critique of the FAA's propagation models.

This section supplements the information provided in Appendix C to the FAA Report. LightSquared had a very short period of time – about a week – to provide inputs to the FAA's propagation model contained in the FAA Report. While LightSquared managed to get most of its key inputs incorporated in this short time, the task was made more difficult by the FAA revising its version of the propagation model while LightSquared was preparing its inputs. Additional analysis and comments from LightSquared on the FAA Report are found in Appendix

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[33] FAA Report [1], at Section 3.2.3.

[34] FAA Report [1], at Section 3.2.3.

[35] The substance of the January 13, 2012 draft version is substantively the same as the FAA Report for purposes of Dr. Parson's review.

C thereto. Now that a final FAA propagation model is available in the FAA Report and LightSquared has had more time to analyze it, it is possible for LightSquared to provide a more detailed critique of the FAA propagation models.

### A. Procedural Background

The FAA had previously requested the RTCA to perform a study on the same subject, which resulted in the RTCA Report.[36] The final report from this study recommended a "minor" follow-on study to close out some open items, which included (i) a probability analysis of the cumulative distribution function ("CDF") of the RFI power at the GPS receiver; (ii) a finer determination of the aircraft height corresponding to maximum RFI; and (iii) a determination of the acceptable RFI thresholds for both tracking and inflight acquisition.[37]

### B. The FAA Report adopted significant changes in its new propagation model and criteria relative to RTCA study

The follow-on work was not performed by the RTCA but by the FAA itself, using a combination of its own staff and some consultants who had participated in the previous RTCA study. During this work, several fundamental aspects of the RTCA Report were changed completely and new criteria were introduced. The changes in the RTCA Report relative to the FAA Report are discussed below. LightSquared agreed with some of the changes but disagrees with many, as described below.

The FAA Report adopts significant changes in key modeling assumptions, parameters, and operational criteria, not considered in the RTCA Report, which were not able to be fully reviewed by LightSquared prior to publication of the FAA's Final Report, including:

- New propagation models and model-parameters.[38]
    - A propagation model was introduced, whose parameters (breakpoint distances) were based on the probability of line of sight to the base stations. In the previous model, the breakpoints were also arbitrary, (unsupported by empirical data) but were based exclusively on path geometry.
    - The extended Suzuki model was introduced over the normal Suzuki model used previously. The extended Suzuki model was developed for MSS links whereas the normal Suzuki model was intended for cellular links.
    - There was recognition that the standard deviation could not be modeled simply as 8.4 dB, based on the assumption of a narrowband base station signal.[39]
    - The standard deviation of received RFI power was made dependent on the lateral distance.[40]

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[36] RTCA Report [3].

[37] RTCA Report [3], at Executive Summary.

[38] FAA Report [1], at Appendix B.

[39] RTCA Report [3], at Appendix B, Section B.2.1.2.

[40] The lateral distance is measured from the base station to the nadir point below the aircraft.

- There was a significantly different treatment of the low altitude cases (300 ft and lower). There was much greater use of low-loss models, such as free space and 2-ray, than in the RTCA Report, where lossy clutter-models were used. No reason was provided for the change. The low-loss assumptions about low altitude use-cases shifted the critical height (of maximum RFI power) to lower altitudes. This was compounded by the fact that many Sprint base stations[41] were found to exist in areas assumed in the RTCA Report (apparently erroneously) to be free of base stations to conform to Obstacle Clearance Surface ("OCS") criteria.
- The new propagation model was made *site specific* whereas the old model was *zone specific*. Here, "site" refers to the nadir point of the aircraft and "zone" refers to a circular annular region around the nadir point. This change was necessary because it was found that highly built up areas near major airports presented special cases of high RFI that could not be adequately represented by the model of *uniform base station density per zone* assumed in RTCA Report.

- There was recognition that the base station emits linear, horizontally and vertically polarized signals and that these have different responses in the GPS antenna.

- TAWS was introduced very late in the process. This became quickly the critical requirement, dwarfing all others in terms of driving base station EIRP reductions.

In addition, unlike the RTCA Report, the FAA Report contains several propagation models based on differing aircraft height that may be categorized as follows:

- From approximately 300 ft to 1755 ft (535 m), the *aggregate base station RFI model* is used. LightSquared refers to this as the Higher Altitude model (to distinguish it from the High Altitude model and the Low Altitude models described below).

- Above 535 m, where the High Altitude model applies, the pure free space pathloss model is used for all base stations in the radio horizon. This is one of the few areas where the FAA Report and RTCA Report have remained identical and there is no disagreement between the FAA and LightSquared.

- Below 300 ft (~100 m), where there is a direct LOS to the aircraft, the FAA has performed calculations using both pure free space and the 2-ray model. The FAA has not taken a stand on which model should be used in which scenario. In this section, LightSquared refers to this as the Low Altitude model.

### 1. Higher Altitude Model – FAA Report

This model is described in the FAA Report, Section 3 and Appendix B. The general methodology is as follows.

[41] At the time of the FAA analysis, LightSquared's base station deployment was expected to largely be an overlay of the existing Sprint network.

A Monte Carlo simulation is performed where each base station produces RFI power samples with a given median value (μ) and standard deviation (σ), the probability distribution being given by an extended Suzuki distribution. The values of μ and σ are determined both by the path geometry and the specific distribution of base station locations and heights visible from the GPS receiver. These aspects are described further in Section 3.2 of the FAA Report. The above shows that the propagation model is site specific, unlike the model in the RTCA Report, which was site-neutral.

The net RFI power at the GPS receiver is calculated as the sum of the power contributions from all base stations within the radio horizon. The extended Suzuki distribution mentioned above is the distribution of the product of two independent random variables, the first having a Rician distribution and the second having a lognormal distribution. In the normal Suzuki distribution, the first random variable has a Rayleigh distribution. In its intended usage mode,[42] the first variable represents fast fading and the second variable represents slow fading.

### 2. Higher Altitude Model - RTCA Report

The methodology of the RTCA Report is reviewed below as background, as it created the framework on which the methodology of the FAA Report is based.

The RTCA's propagation model for the Higher Altitude scenario was based on multiple segments with different μ and σ. Figure B.II.1 illustrates the segments and breakpoints for BTS tower height of 30m, and aircraft height of 535.2m.

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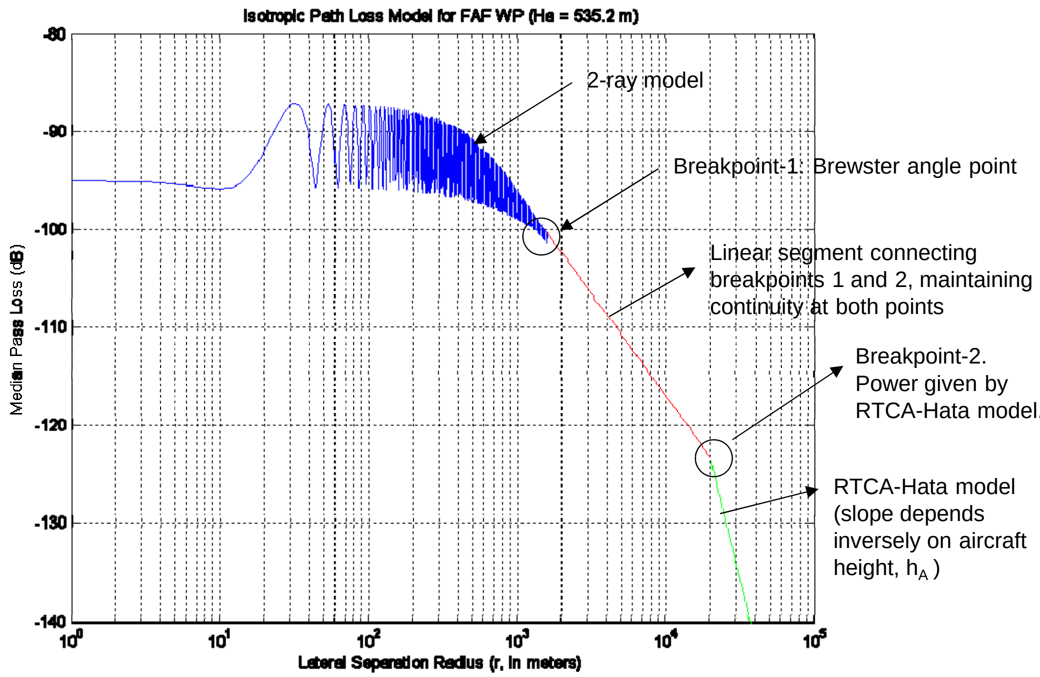
[42] It is noteworthy that neither the Suzuki distribution nor its extension stipulates how each variable must vary with time (for an observation point that is time varying, i.e. mobile) or with distance, which is the more fundamental variable).

**Figure B.II.1 Breakpoints in FAA's Higher Altitude Propagation Model in RTCA Report**




### a) Segment-1 (2-Ray Model)

The first segment extends from d=0 to d=$r_1$, where d is the lateral distance of the base station from the aircraft's nadir point. The breakpoint $r_1$ is chosen to correspond to the distance at which the Brewster angle occurs, i.e. the distance where the reflection coefficient for vertical polarization becomes zero. No physical reason is advanced by the FAA as to why the 2-ray model should be used up to this point – the sinusoidal variations of the received field strength continue beyond this distance until they decay to a point beyond which the received power falls off with distance with an exponent of 4.[43]

The distance, $r_1$, is dependent on the path geometry – for lower aircraft heights, $r_1$ is smaller. For example, for a base station height of 30 m, $r_1$ assumes the following values for the aircraft heights considered in RTCA Report.

**Table B.II.1 First Breakpoint Distances for 30 m base station height**

| Aircraft Height (m) | First Breakpoint Distance (m) |
|---|---|
| 535.2 | 1597 |
| 53.3 | 222.9 |
| 25.9 | 190.18 |
| 4.0 | 97 |

[43] Rappaport, T.D., Wireless Communications Principles and Practice (2 Ed.), Prentice Hall, 2002, at 124 [6].

### b) Segment-2 (Linear Connecting Segment)

This is an artificial segment for which the FAA has not provided any physical justification. The only justification seems to be the mathematical one of ensuring continuity across segment boundaries. It joins the pathloss values at the end of segment-1 and start of segment-3 with a straight line (relative to a logarithmic distance axis). The end of segment-1 has a pathloss corresponding distance at which the Brewster angle occurs and the start of segment-3 has a pathloss given by the RTCA Hata model. The slope of segment-2 can be as low as 2.09 and as high as ~ 4 for different scenarios, as shown below.

**Table B.II.2 Second Breakpoint Distances for 30 m base station height**

| Aircraft Height (m) | Second Breakpoint Distance (m) | Segment-2 slope | Elevation Angle (BTS to aircraft) in degrees to 2nd breakpoint |
|---|---|---|---|
| 535.2 | 20000.0 | 2.089 | 1.44 |
| 53.3 | 1000.0 | 2.923 | 0.13 |
| 25.9 | 190.18 | 3.564 (Hata model slope) | -1.2 |
| 4.0 | 1000.0 | 3.983 | -1.49 |

For an aircraft height of 25.9 m, segment-2 vanished as the Hata model loss at 190.18 m was the same as that at the end of segment-1 and a connecting segment was unnecessary.

### c) Segment-3 (RTCA adapted Hata-Okumura model)

The FAA used a clutter based propagation model when the elevation angle was sufficiently low. LightSquared agreed with this. However, the distance at which the clutter model should be used was arbitrary – as Table B.II.2 shows, there is no systematic dependence on the magnitude of the elevation angle, which could have been a plausible criterion, based on the assumption that a lower elevation angle increases the probability of blockage, and therefore the applicability of a cellular-like median pathloss law.

While the above description only refers to two breakpoints, there is also a 3rd breakpoint at a distance of 20 km where the extended Hata model increases the median pathloss slope slightly. For the case where the aircraft height is 535.2 m and the 2nd breakpoint is itself at 20 km, the 2nd and 3rd breakpoints merge.

The Hata-Okumura propagation model was modified by the RTCA in a number of ways, some of which were arbitrary.[44] These included:

i. Using the tall antenna mode of the Hata model (which allows antenna heights up to 550 m) and reversing the propagation direction

[44] RTCA Report [3], at Section B.3.1.1.2.

ii. Using the ITU-R extension for ranges greater than 20 km
iii. Using an antenna factor, AF, corresponding to urban scenarios but choosing the suburban option for the main equations (B-15 and B-17)
iv. Using the model beyond the specified frequency range of 150 – 1500 MHz, and refusing to use the COST 231 model which is recommended for the frequency range applicable for LightSquared's frequency ranges (1525 – 1660.5 MHz).

No physical justification was provided for (iii) and (iv), beyond that they yielded larger values of pathloss, which were "deemed unlikely" in the opinion of the RTCA. The record of discussions between LightSquared and the FAA on the subject of propagation models, including an opinion by Dr. Parsons, whose book was referenced by both reports, is provided in Attachment B-2.[45]

It is noteworthy that the suburban correction reduces the pathloss by 11.5 dB relative to a large/medium city, as shown in the following case.

Area correction factor K= 2[log10(fc/28)]^2 +5.4 for Suburban area.
K = 0 for Medium and Large city
For $f_c$= 1531 MHz, K = 11.4 dB for suburban area.

The FAA's argument was that airports are typically located in suburbia; hence the suburban correction factor is appropriate. However, at the same time, it used the antenna correction factor for urban scenarios. To quote Dr. Parsons:[46]

> If it is sensible to use the "large city" antenna height expression, then to be consistent with this we should not apply the suburban correction factor to the environment. To "mix and match" like this is not good engineering practice and casts doubts on the robustness of the model – it could be construed as a license to choose whatever parameters are necessary to make the model fit a certain data set.

From the above, the general pattern of the arbitrary ways in which the FAA assessed compatibility, even in the RTCA report, includes the following:

- Parameters were chosen in existing propagation models in an arbitrary and sometimes self-contradictory ways. Examples:
    - Use of the Hata-Okumura model outside its specified frequency range when COST231 model was available for the appropriate frequency range.
    - Use of the suburban option in the main equation and the urban option for the antenna factor

- Existing, industry-standard models were modified in arbitrary ways. No empirical data was advanced to support the choices.
    - The 2-ray model was used until the Brewster angle and the RTCA modified Hata-Okumura model was used from another arbitrary distance. The two segments

45 Fizzle Technologies, "The LightSquared Comments on the use of the Hata Propagation Model," (Sept. 11, 2011) [7].
46 Parsons, J.D. and Gardiner, J.G., Mobile Communication Systems, Blackie & Sons Ltd., 1989 [11].

> were joined together by a straight line, whose slope could approach 2.0 for an aircraft height of 535 m. This implies free space propagation. However, this was used with a standard deviation of 8.4 dB[47] which is without any support for a LOS link.

The net effects of these choices, relative to other equally plausible (or more plausible) choices that could have been made, were sometimes in excess of 10 dB. This is remarkable considering that the RTCA report concluded that, for the lower 10 MHz channel, the link margin shortfall for median pathloss, in the in-flight acquisition mode, was only 3.5 dB and that there was a 2.5 dB positive margin for the Tracking mode. It should be clear from the above that <u>the analytical methods used by the RTCA lacked the certainty to draw such fine-grained conclusions that the FAA is now attempting to draw in the FAA Report</u>. Moreover, the assumptions made appear to have been biased towards maximizing the received RFI power.

### C. The FAA's methodology is flawed

In the FAA Report, as in the RTCA Report, the FAA persisted with a model where the median pathloss varied as a continuous function of log(lateral distance), in piecewise linear segments.[48] However, the breakpoints and the segment characteristics (median value and standard deviation) were different from the RTCA report. Figure B.II.2 shows an example of the median pathloss profile for DCA-1 and DCA-2 scenarios, assuming the aircraft is at a height of 76 m and the base station antenna height is 45 m. As in the RTCA report, the received RFI power analyses were based on Monte Carlo simulations.

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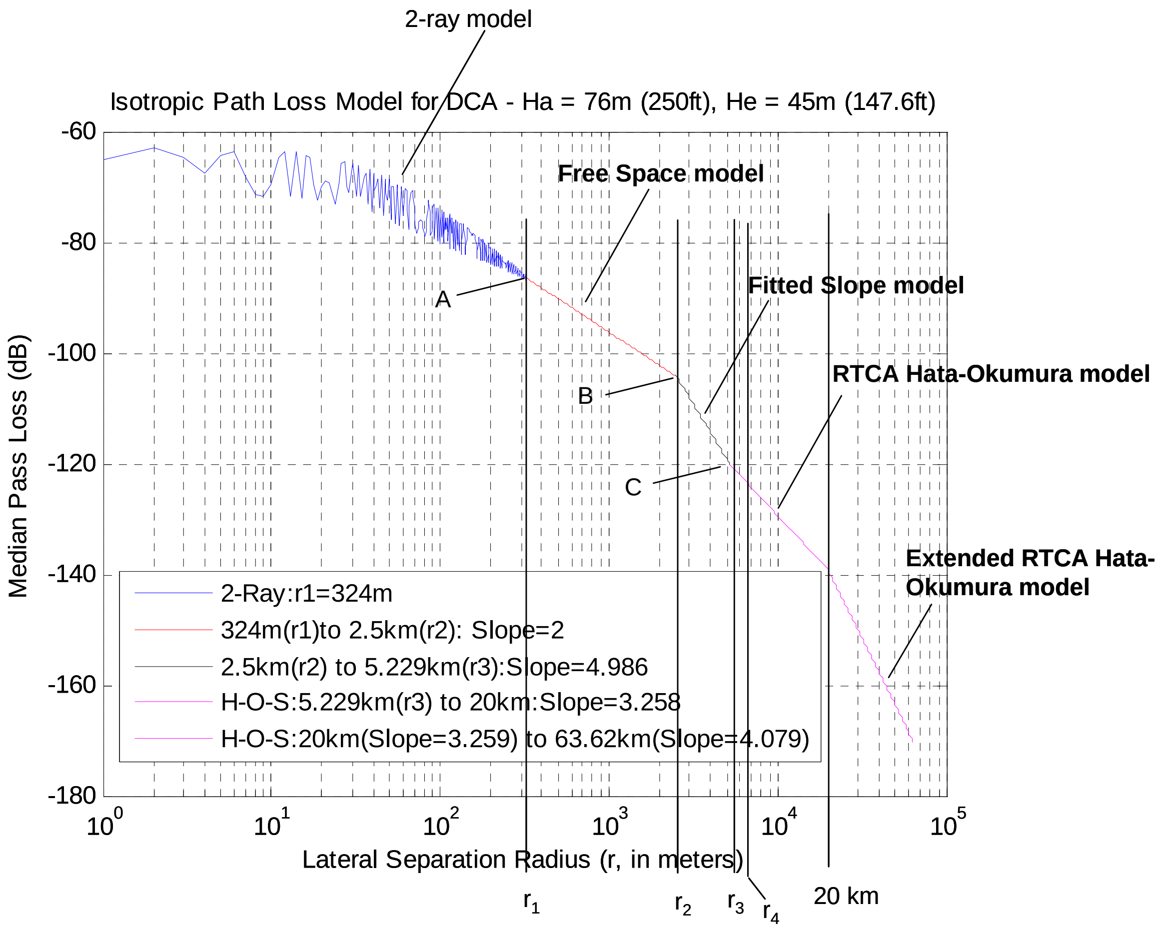
[47] In the FAA Report the standard deviation was reduced for smaller lateral distances. However, the pattern of using relatively high standard deviations on links with low excess loss over free space continued.

[48] FAA Report [1], at Appendix B.

**Figure B.II.2 Median Pathloss Profile for DCA according to the FAA Propagation Model**




A purely mathematical model such as the above may be justified when no information is available about the actual distribution of base station locations and antenna heights, as was the case in the RTCA report. However, when site-specific information is available, as in the FAA report, this information *can* and *should* be utilized, as it leads to a more accurate estimate of the RFI power. The FAA models in its report were made *partially site-specific*, i.e. they used site-specific information about the likelihood of encountering blockage (for a given path geometry[49]) but assumed that all base stations at a given lateral distance, *regardless of their blocked/unblocked status*, contributed the same median RFI power and had the same standard deviation of RFI power. Whether a model such as this will yield an accurate estimate of the actual net RFI power is critically dependent on the functions assumed for median pathloss and standard deviation. This is acknowledged by the FAA in Section 3.3.4 of the FAA Report where

[49] The path geometry is determined by aircraft height, lateral distance to the base station from the nadir point and the base station antenna height.

the sensitivity of the results to Monte Carlo simulation parameters is discussed.[50] Yet, the functions proposed by the FAA were not associated with any empirical support, their only requirement being continuity across breakpoints, e.g. at points A, B, and C in Figure B.II.2.

In contrast, LightSquared proposed a propagation model that is much closer to physical reality, being based on free space propagation and, for blocked links, an additional loss of 10 dB based conservatively on MSS propagation literature and other sources, such as ray tracing and theoretical estimation based on the theory of radar cross sections. In this model, the link to each base station is examined individually and, based on a morphology database, a determination is made if the link is *blocked* or *unblocked*. If the link is blocked, one set of median power and standard deviation values is used; if it is unblocked, another set is used. Both of the above sets are derived from empirical data obtained from the MSS propagation literature. Appendix C of the FAA Report, which contains the LightSquared view, provides more details about this model and its justifications (which included ray tracing and other methods beyond MSS propagation literature). Specifically, the parameter values, supported by empirical data from MSS field trials were[51]:

- Blocked
    - Mean pathloss = free space loss + 10 dB
    - Standard deviation = 3.5 dB

- Un-blocked
    - Mean pathloss = free space loss
    - Standard deviation = 0.5 dB

The FAA's models for median pathloss and standard deviation[52] are described below.

### 1. Median Pathloss

#### a) First breakpoint ($r_1$)

The first segment extends from the nadir point to the point at which the Brewster angle of the 2-ray model occurs (as in the RTCA report). The distance to this point is $r_1$.

#### b) Second breakpoint ($r_2$)

This point is to be determined from the site-specific distribution of the locations and heights of the base station towers around the airborne GPS receiver. The breakpoint, $r_2$, is selected to be the lateral distance up to which "essentially clear LOS" exists to the base stations.

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50 ("The CDF tails (e.g. $10^{-6}$ region) results are quite sensitive to the modeled sigma-dB values. In view of this sensitivity, a modeling change to the continuous distribution was made after it was observed that the large CDF tails were being driven in part by the step-sigma value of 6.4 in the region slightly above 20 km. The associated abrupt step change was judged not to be physically reasonable.")

51 Loo, C., "A Statistical Model for a Land Mobile Satellite Link," *IEEE Transactions on Vehicular Technology* Vol. 34, No. 3 (August 1985) [8].

52 FAA Report [1], at Appendix B.

In the Washington DCA-1 and DCA-2 scenarios, this was determined to be 2.5 km. The method is clearly far from rigorous – there is not even a definition of what "essentially clear LOS" means. A factor known as "S" is used in the MSS literature, which could have been used.[53] The S-factor defines the probability of encountering blockage, i.e. S=1 means 100% probability of blockage and S=0 means 100% probability of clear LOS (no blockage). A low threshold value of S could have been set to define an objective basis of selecting the second breakpoint.

Between the first breakpoint, $r_1$, and the second breakpoint, $r_2$, the median pathloss is assumed to vary according to an inverse square law (exponent of 2.0), consistent with free space propagation. This is not unreasonable, given that $r_2$ is selected on the basis of a low S-factor.

### c) Third Breakpoint ($r_3$)

The FAA's determination of the third breakpoint, $r_3$, is purely an exercise in mathematics without any attempt at an empirical justification. The selection algorithm is as follows:

- $r_3$ represents a distance where the blockage factor, S, becomes "substantial," although (as above) a quantitative definition of S at $r_3$ is lacking.

- The median pathloss value for $r_3$ must satisfy the RTCA Hata-Okumura equation to maintain continuity across breakpoints (the segment beyond $r_3$ corresponds to the RTCA Hata-Okumura equation). In other words, C (in Figure B.II.2) must land on the RTCA Haka-Okumura line.

- $r_3$ has a minimum value, $r_{3min}$, which occurs for an aircraft height ($h_A$) of 30 m. For the DCA scenarios, $r_{3min}$ is 5 km and $r_3$ is 5.23 km

- The line joining $r_2$ and $r_3$ is a straight line with a slope given by an equation.[54] For the DCA scenarios, the slope is 4.986, not 5.76 as stated in the RTCA Report.[55]

- The above equation makes the slope dependent on the path geometry, with a lower slope for greater aircraft height. Presumably, the heuristic justification of this rule is that S will reduce as $h_A$ is increased. What this means, effectively, is that as $h_A$ increases, $r_3$ increases. For the DCA scenarios, $r_3$ = 5.229 km.

### d) Fourth Breakpoint ($r_4$)

The fourth breakpoint is not related to the slope of the median pathloss curve – it is part of the standard deviation model. It is the point at which the standard deviation, given by an assumed polynomial, reaches the value of 6.4 dB. This is assumed to be the standard deviation

[53] Goldhirsh, J. and Vogel, W.J., "Propagation Handbook for Land-Mobile-Satellite Systems," Report SIR-91u-012, Johns Hopkins University Applied Physics Laboratory, at Chapter 11, 1991 [9].

[54] RTCA Report [3], at Section B.3.3.

[55] RTCA Report [3], at B-5.

in the segment where the RTCA Hata Okumura pathloss model holds. The method of defining standard deviation is discussed below in more detail.

### 2. Standard deviation of pathloss

It is noteworthy that the FAA used independent compatibility criteria for the median RFI power and the RFI power received with a probability of 1E-6 assuming a lognormal distribution. The standard deviation drives the second compatibility factor (RFI power at P=1E-6), which is the more challenging factor based on the models/ parameters assumed by the FAA. Yet the FAA makes no attempt to offer any empirical basis for the hypothetical *standard deviation versus lateral distance* function. This function is a polynomial fitted to a step function of σ values in different segments as shown in the FAA Report.[56] The choices of the discrete σ values are arbitrary and physically unrepresentative, as discussed below. The only requirement for the σ versus distance function is to reach a value of 6.4 somewhere beyond $r_3$, where the median pathloss is determined by the RTCA Hata-Okumura model.

The standard deviation functions are shown in the FAA Report, Figure 3-9 for the LAKIE scenario (aircraft height of 535 m) and Figure 3-20 for the DCA scenarios (aircraft height of 100 m). While for LAKIE, the limiting standard deviation of 6.4 is achieved at a distance of 20 km, where significant blockage and scattering may be expected, for the DCA scenario, the limiting standard deviation of 6.4 is achieved at approximately 6 km. This means that LOS links may exist at this distance and they would be assigned a standard deviation of 6.4. Physically, this is extremely unlikely and the FAA has provided no empirical justification for this model. The fallacy of this approach is shown in more detail, with specific examples, in Section III.C.4.

A fundamental area of disagreement between the FAA and the LightSquared propagation models is whether high standard deviation (barring the fast fading component caused by local multipath) and low median pathloss (approaching free space values) can exist simultaneously. The FAA's position that such cases *can* exist is without support in the empirical propagation literature. In contrast, LightSquared's position is supported by several MSS propagation measurements. See Appendix C of the FAA Report for a detailed discussion of the support in the MSS literature for the LightSquared position. A summary position may be stated as follows.

> When there is a direct LOS link, it is well known that the fading is Rician with a large K-factor (carrier to multipath ratio) and a standard deviation around 0.5, as shown by the MSS literature.[57] The smaller K factors are obtained when there is significant blockage/shadowing of the direct ray, leading to a larger standard deviation. Yet, the FAA persisted in using relatively large values of σ with low excess path loss over free space. Specific examples of such cases are shown in Section III.C.4.

On a side note, <u>the notion that the standard deviation should increase monotonically with distance also lacks empirical support</u>. There are many examples in both the LAKIE and DCA

[56] FAA Report [1], at Equation 7.

[57] *See e.g. L*oo [8], Goldhirsh et al. [9].

scenarios where the blockage (represented by S) actually reduces with distance. There are also examples in the cellular propagation literature where the standard deviation has been found to reduce with distance for certain urban locations, e.g. when an open area is encountered in the propagation path following a built up area.[58]

### 3. Fast Fading

In both the normal and extended Suzuki distributions, the first random variable is associated with *fast fading* in cellular and MSS scenarios, respectively. Such fading is associated with multipath reflections from surfaces in the immediate vicinity of the receiver (local clutter). Clarke's foundational paper provides a good physical explanation and mathematical model for multipath induced fast fading in cellular environments.[59] In such environments, multipath reflections around the base station do not contribute as much to fast fading.[60] To quote from the above reference:

> The reciprocity theorem applies, of course, in any linear medium, but this should not be taken to imply that the spatial correlation distance at one end of the radio path is the same as it is at the other.

Intuitively, this can be explained by noting that a small movement in the position of a mobile receiver in a substantially multipath-free local environment, such as an open field, does not create a large decorrelation of the received field, even when the base station may be surrounded by clutter (reflecting surfaces). Figures B.II.3 and B.II.4 illustrate why the LightSquared RFI scenario should not include fast fading. The figures show a single transmitter/ receiver path as an illustration of the propagation mechanism. In the LightSquared scenario, where a plurality of base stations would exist, the presence of multiple transmitters only affects the net received power, because the signals from different transmitters are uncorrelated.

In the LightSquared scenario, there is almost no time varying local multipath at the GPS receiver which is on an aircraft in level flight.[61] Any time varying multipath, as the aircraft moves through the received field, would be caused by clutter *at the source*, i.e. around the base station. From the path geometry, illustrated in Figures B.II.3 and B.II.4, it should be clear that the fading can only be *slow* (the decorrelation distance is not sub-wavelength, as is typical in fast fading and shown by Clarke). In the act of reversing the propagation direction, in order to use cellular and MSS propagation models, the FAA also assumed that the local multipath conditions at the receiver and transmitter could also be exchanged. This is clearly an error and has led to its assumption that, as in the cellular and MSS channels, the LightSquared RFI channel will also include fast fading. <u>LightSquared believes that there should be no fast fading component in the</u>

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[58] Parsons, J.D, <u>The Mobile Radio Propagation Channel (2 Ed.)</u>, John Wiley and Sons, Chichester, UK, 2000, at 155 [5].

[59] Clarke, R.H, "A Statistical Theory of Mobile-Radio Reception," 47 Bell Systems Technical Journal 6, pp. 957-1000 (1968) [4].

[60] Parsons et al. [11], at 40-41.

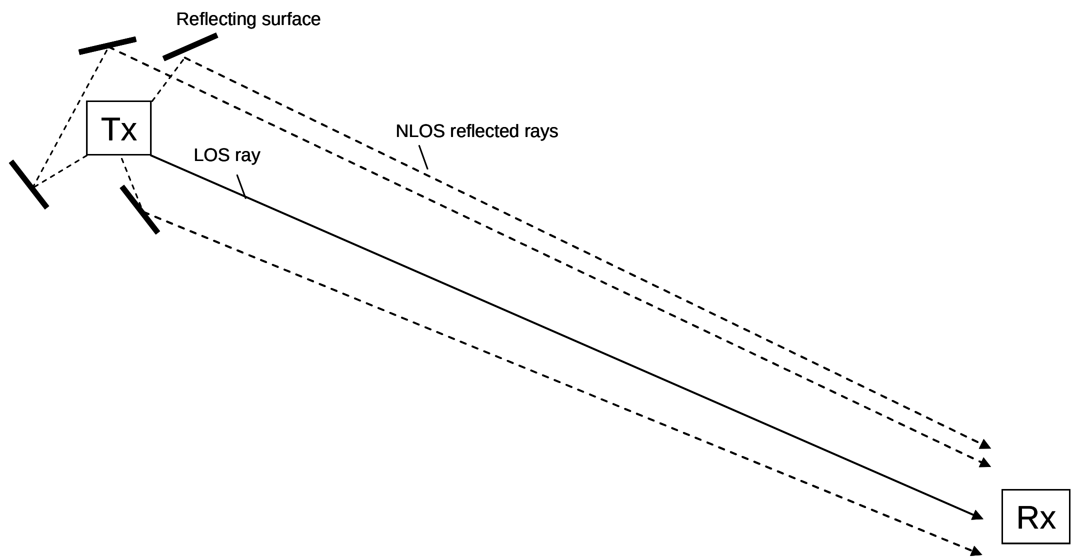
[61] There may be local reflections from the body of the aircraft but they are not time varying when the aircraft is in level flight.

<u>channel model</u>. However, the <u>FAA has chosen to retain the fast fading component in the extended Suzuki propagation model, while providing no supporting rationale.</u>

Fortunately, based on the FAA's particular choice of parameters, the fast fading effects on the median RFI power and the tail of the CDF curve of RFI power, evaluated at P=1E-6, is relatively small. Therefore, the erroneous assumption of a fast fading component in the channel model is non-critical in determining compatibility, further demonstrating the arbitrary nature of the FAA's choice in propagation models.

**Figure B.II.3**

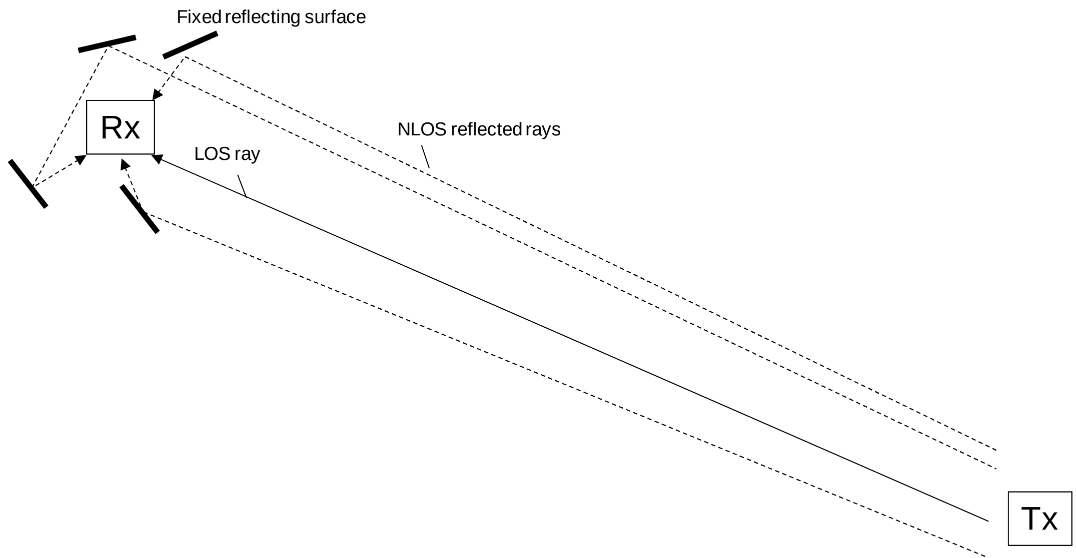
Fading scenario with clutter around Tx. (plan view)




Small movements in the Rx position do not cause much field decorrelation in this scenario. The fading caused by Rx movement is therefore <u>slow</u>. The LightSquared RFI scenario is the same as this with the Rx being the airborne GPS Rx.

**Figure B.11.4**

Fading scenario with clutter around Rx. (plan view)




Small movements in the Rx position cause significant decorrelation in the field components in this scenario [4]. The fading caused by Rx movement is therefore <u>fast</u>. This represents a cellular/MSS propagation environment, not the LightSquared RFI scenario. In the latter, it is the Tx (base station) that is surrounded by local clutter, not the Rx (GPS device). Nevertheless, the FAA's propagation model erroneously includes a fast fading component.

### 4. Examples of pathloss and standard deviation values calculated by FAA and LightSquared models

This section provides some examples of median pathloss and standard deviations for particular base station to aircraft links in the DCA scenarios in the third ($r_2 – r_3$) segment. The examples have been selected to highlight the anomalous consequences, from a physical standpoint, of the FAA's propagation model. The mean pathloss and standard deviation values calculated by the FAA and LightSquared models are shown in Table B.II.3 below, together with their blocked/unblocked status based on actual morphology.

**Table B.II.3 Values of Median Pathloss and Standard Deviation calculated by FAA and LightSquared Models**

| No. | Base Station ID | Blocked/Unblocked | Base Station Antenna Height above Sea Level (m) | Distance from nadir point (km) | FAA Values | | LightSquared Values | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Median pathloss (dB) | Pathloss Standard Deviation | Median pathloss (dB) | Pathloss Standard Deviation |
| 1 | DC03XC012 | Blocked | 49.4 | 3.276 | 109.16251 | 2.0057885 | 116.45141 | 3.5 |
| 2 | DC03XC199 | Unblocked | 139.4 | 3.457 | 106.35737 | 2.2077435 | 106.91611 | 0.5 |
| 3 | WA23XC515 | Blocked | 51.43 | 2.571 | 104.56431 | 1.3407274 | 114.34501 | 3.5 |
| 4 | WA57XC011 | Unblocked | 65.89 | 2.577 | 104.78052 | 1.3460329 | 104.36661 | 0.5 |
| 5 | WA73XC422 | Blocked | 36.81 | 5.110 | 119.1558 | 4.6812924 | 120.31156 | 3.5 |
| 6 | DC03XC179 | Unblocked | 156.11 | 5.149 | 108.30565 | 4.7518218 | 110.37652 | 0.5 |

The examples in Table B.II.3 have been selected as pairs of cases with similar lateral distance. It will be observed that, at shorter distances such as cases 3 and 4 (around 2.5 km), even when the link is blocked, the median pathloss is very similar to free space (approximately 104 dB). Such cases significantly increase the net RFI power in the FAA model without any physical justification. In the case of relatively large distances, when the link is unblocked, the FAA model assumes a large standard deviation (e.g. 4.75 in case 6) while its median pathloss (108 dB) is 2 dB less than the free-space pathloss (110 dB), also without any physical justification. In contrast, the LightSquared model uses a standard deviation of 0.5 based on the MSS literature for the same case.[62] The above examples show the fallacy of basing the median pathloss and standard deviation on lateral distance and path geometry, which is the model adopted by the FAA, instead of the actual blocked/unblocked status of the base station to aircraft link, as is the method of the LightSquared model.

In summary, if site-specific base station and morphology data *are* available, as is assumed in the FAA propagation model in the FAA Report, it makes little sense to use it *partially* (i.e. to determine the breakpoints) and then force a uniform mathematical model onto *all* base station to aircraft links.

[62] Loo [8].

### D. Summary of deficiencies in the FAA's higher altitude propagation model in FAA Report

The following is a list of deficiencies of the FAA's higher altitude propagation model.

1. Partial use has been made of the site-specific blocked/unblocked status of base station antennas relative to the height of the aircraft. The information is used only to derive the breakpoints of the median pathloss and standard deviation functions relative to distance. These functions appear to be completely arbitrary – no physical justification has been offered. Given that *a priori* knowledge of the blocked/unblocked status of base station antennas is necessary in the FAA model, the LightSquared model, also utilizing this information, is closer to physical reality and is supported by MSS propagation literature.

2. The arbitrariness of the FAA model exists in multiple dimensions, as listed below.

   a. In the FAA model, the median pathloss from a base station depends only on lateral distance from the nadir point of the aircraft and path geometry, not on the blocked/unblocked status of the path. This leads to blocked base stations at small lateral distance having close to free space loss. This causes the median RFI power to be overestimated.
   b. The standard deviation increases with distance, but the function depends on aircraft height. The nature of the above dependence is such that, at low aircraft heights (e.g. 100 ft), an unblocked base station at approximately 6 km could be assigned a standard deviation of 6.4 dB. The MSS literature suggests that the standard deviation for LOS conditions should be 0.5 dB. The high standard deviation severely impacts the criterion based on the tail of the CDF of RFI power. A high standard deviation also increases the mean RFI power.
   c. A fast fading component has been included by borrowing the extended Suzuki model from the MSS propagation literature. Including fast fading in the LightSquared environment is without physical basis as the reversal of the propagation direction between the transmitter and the receiver (assuming that the aircraft is the transmitter and the base station the receiver) does not cause the local multipath environments to also be exchanged. Without significant local multipath at the receiver there cannot be fast fading.[63] The impact of this error appears to be small, but still noticeable in the compatibility assessment.
   d. The Hata-Okumura model has been applied outside its specified frequency range, rejecting the industry standard COST231 model, which would have been appropriate for the frequency range applicable to the LightSquared frequencies. The COST231 model would have yielded significantly greater pathloss.
   e. The parameters of the Hata-Okumura model have been chosen in ways that appear to be arbitrary and self-contradictory, with the net effect of increasing the pathloss by approximately 11 dB in some scenarios. For example, <u>in the DCA and LGA</u>

[63] It is acknowledged that some fast fading (frequency dispersion) exists even for fixed receivers, caused by movements in the environment, such as the rustling of leaves caused by wind and movements of vehicles. However, such fading has an order of magnitude smaller standard deviation than fading caused by the movement of the transmitter or the receiver.

scenarios, where the airports are surrounded by urban environments, the Hata-Okumura Urban model would seem to be the obvious and clearly justifiable choice. Yet the FAA chose the Suburban model instead. Also, the suburban equation is chosen in the main equation while opting for the urban antenna factor (called "large city factor" in the Hata formulation).

f. In an attempt to justify the use of a common mathematical model for all base stations, a monotonically increasing function of lateral distance was used to characterize standard deviation. This runs counter to measured data in the cellular industry where it has been found that the standard deviation depends more on the building density than on distance from the base station – in some cases the standard deviation may actually decrease with distance. This is another proof that the approach of forcing common mathematical functions (*μ versus distance* and *σ versus distance*) on all base stations is fundamentally flawed. Each link needs to be individually characterized regarding μ and σ according to its blocked/unblocked status.

### E. Results of FAA and LightSquared propagation models

In this section we examine the results of the FAA and LightSquared Higher Altitude propagation models for the LAKIE (aircraft height of 535 m) and DCA-1 and DCA-2 scenarios (aircraft height of 100 m).

The maximum tolerable RFI objectives stated by the FAA in the FAA Report are as follows.[64]

Tracking:

- Mean interference level must be at or below -34.1 dBm for an aircraft at level attitude. This reflects a 6 dB margin below the receiver susceptibility of -28.1 dBm to account for non-modeled effects and random events.

- Probability of interference level exceeding -30.1 dBm must be $\leq 10^{-6}$ in any hour of flight, considering aircraft banking and pitching. This preserves a 2 dB margin in RF interference for non-modeled effects other than LightSquared.

Acquisition:

- Probability of interference level exceeding -34.1 dBm must be $\leq$ 0. 001 for an aircraft at level attitude.

The FAA and LightSquared agreed that, a 4 dB correction factor was sufficient for accommodating the effects of standard banking (25%) relative to level flight for the GPS antenna reference pattern used in the study.[65] The FAA has assumed the presence of banking in the low altitude DCA scenarios although this is quite unrealistic for an aircraft at a height of about 300 ft and lower. However, to create a comparison of like scenarios in the following analysis, LightSquared has first assumed the presence of banking and then looked at the consequence of

[64] FAA Report [1], at Section 1.3

[65] RTCA Report [3], at Figure 1-1, ATCt Base Station Transmit Antenna Patterns.

removing it. The compatibility with banking may be estimated simply by increasing the received RFI power at P=1E-6 by 4 dB.

**Table B.II.4 Results of Higher Altitude FAA and LightSquared Models (Base station EIRP's at 32 dBW)**

<table>
<tr><th rowspan="2"></th><th rowspan="2">Maximum Passing Level</th><th colspan="2">Lakie (Aircraft Height = 535 m)</th><th colspan="2">DCA-1 (Aircraft Height = 95.1 m)</th><th colspan="2">DCA-2 (Aircraft Height = 121.9 m)</th></tr>
<tr><th>FAA</th><th>LS</th><th>FAA</th><th>LS</th><th>FAA</th><th>LS</th></tr>
<tr><td>Tracking: Mean (dBm)</td><td rowspan="2">-34.1</td><td>-37.5</td><td>-38.89</td><td>-33.6</td><td>-34.28</td><td>-34.4</td><td>-35.1</td></tr>
<tr><td>Margin (dB)</td><td>3.4</td><td>4.79</td><td>-0.5</td><td>0.18</td><td>0.3</td><td>1.0</td></tr>
<tr><td>Tracking: P=1E-6 (dBm)</td><td rowspan="2">-30.1</td><td>-31.1</td><td>-34.77</td><td>-26.9</td><td>-28.92</td><td>-26.7</td><td>-29.65</td></tr>
<tr><td>Margin (dB)</td><td>1.0</td><td>4.67</td><td>-3.2</td><td>-1.18</td><td>-3.4</td><td>-0.45</td></tr>
<tr><td>Acquisition: P=1E-3</td><td rowspan="2">-34.1</td><td>-37.0</td><td>-38.82</td><td>-32.3</td><td>-33.8</td><td>-32.7</td><td>-34.75</td></tr>
<tr><td>Margin (dB)</td><td>2.9</td><td>4.72</td><td>-1.8</td><td>-0.3</td><td>-1.4</td><td>0.65</td></tr>
</table>

It can be seen from the above that the margins are greater for the LightSquared model. The difference between the models is greater at the higher altitudes. For the lower altitude DCA scenarios, even the LightSquared model yields a small (-1.18 dB) negative margin for the CDF tail for Tracking with banking. If banking is considered unlikely at this height, as discussed above, the margin becomes positive. For Acquisition, there is a very small negative margin (-0.3 dB), which can be easily rectified by reducing EIRP slightly for proximate base stations. When the LightSquared proposal for reducing base station EIRPs to accommodate TAWS is considered,[66] the margins become substantial as shown below (assuming the presence of banking – without banking, the margins for Tracking increase by 4 dB).

It should be pointed out that the DCA-2 scenario (aircraft height of 400 ft MSL) corresponds approximately to the Obstacle Clearance Surface (OCS) at this location, which would represent possibly the worst case. The FAA stated, "the DCA-1 scenario (aircraft height of 312 ft MSL) is used to check for sensitivity of mean aggregate received power to the aircraft antenna height parameter." However, <u>it should be noted that this is a *hypothetical scenario* for DCA as it is below the OCS. Hence, pass/fail determinations should not be based on the DCA-1 scenario</u>.

[66] FAA Report [1], at C-31, Figure C-15.

**Table B.II.5 Results of Higher Altitude FAA and LightSquared Models (Base Station EIRP's reduced to accommodate TAWS)**

| | Maximum Passing Level | DCA-1 (Aircraft Height = 95.1 m) | DCA-2 (Aircraft Height = 121.9 m) |
|---|---|---|---|
| | | LS | LS |
| Tracking: Mean (dBm) | -34.1 | -41.73 | -42.92 |
| Margin (dB) | | 7.63 | 8.82 |
| Tracking: P=1E-6 (dBm) | -30.1 | -36.64 | -37.92 |
| Margin (dB) | | 6.54 | 7.82 |
| Acquisition: P=1E-3 | -34.1 | -41.30 | -42.56 |
| Margin (dB) | | 7.2 | 8.46 |

It is very likely that, with reduced EIRPs, even the FAA propagation model, despite the deficiencies discussed above, will yield positive margins. This verification has not yet been made but has been undertaken by LightSquared and the results are expected shortly. However, the FAA had not discussed LightSquared's proposal for TAWS accommodation, and instead dismissed them as "too difficult to administer." We therefore, now, investigate the veracity of the above claim that LightSquared's proposal for low altitude accommodation is too difficult to administer.

It may appear that given the deficiencies of the FAA's models, the difference with the LightSquared model should have been greater. In fact, they were – when the FAA first presented the results of its new model in the first draft of the FAA Report (December 23 version). The shortfalls for DCA-1 and DCA-2 for the Tracking (P=1E-6) case were 6.9 and 8.0 dB respectively. Between the December 23 version and the final version, the FAA adjusted its models again reducing the shortfalls to their current levels – 3.2 and 3.4 dB respectively. What is clear is a pattern of continuously adjusting the models to attain apparently preconceived notions of what the results ought to be. As the models are not based on any empirical data, there is no barrier to such adjustments.

## III. LIGHTSQUARED'S PROPOSED SOLUTIONS ARE DEMONSTRABLE AND EFFECTIVE

As LightSquared indicated in Appendix C to the FAA Report, it believes that its proposal is reasonable, workable, and effective at addressing the FAA's stated criteria. The proposal presents a reasonable way to manage the dynamic aspects of the system, make adjustments to accommodate changes in operation, and can be monitored effectively to ensure compliance.

The FAA has stated that the low altitude mitigation proposals from LightSquared (both TAWS and takeoff/landing cases) are impossible to administer. This position is scrutinized from the viewpoint of the detailed contents of the models.

With respect to the case of aircraft landing and takeoff, Table B.II.5 above shows that when the EIRP reductions forced by the criteria for TAWS accommodation, described in Section III.B, are taken into account, comfortable passing margins exist for both DCA use cases, as per LightSquared's propagation models described above. When the same EIRP reductions are considered with the FAA's propagation models, which LightSquared does not agree with, it is very likely that passing margins would also exist. LightSquared is conducting simulations to ascertain this.

In addition to the discussion in Appendix C of the FAA Report, the following discussion outlines a general technical methodology to ensure compliance of LightSquared base station emissions toward low-altitude applications of GPS, including approach and departure procedures that rely on GPS for aircraft navigation and TAWS applications, with the objectives of being both (1) technically accurate, and (2) operationally manageable. This methodology may be used to evaluate aggregate emissions from existing base stations, to determine specific base stations that need to operate at reduced power/greater down-tilt, or to determine acceptable locations for placing new base stations. Importantly, the methodology can be adapted to address changing factors (e.g. new procedures/applications of GPS or where additional emission reduction may be desirable).

A proof-of-concept trial of the low altitude navigation methodology was successfully performed using Washington National Airport (DCA) and the existing LightSquared proposed tower database.

### A. Process for ensuring compliance of aggregate base station emissions toward low-altitude aircraft near airports (Low Altitude Navigation)

During takeoff and landing, aircraft in normal glide paths (including appropriate latitudes for such paths) may be subject to relatively high RFI levels from base stations proximate to runways, especially if they are in LOS of the aircraft. In Appendix C to the FAA Report, LightSquared has proposed that it will reduce the EIRP of all such bases stations. It has provided a mathematical model of how such base stations will be identified and their maximum EIRP levels calculated.[67] As in the case of TAWS, the model is completely deterministic. It is more complex than the TAWS model to the extent that the surfaces of descent/ascent can be complex owing to the existence of obstacles around airports. However, to the extent that the surfaces can be defined, even from a worst case standpoint,[68] the base station EIRP reductions can also be defined.

#### 1. Defining Relevant Surfaces

For a given airport, the process begins by defining all relevant GPS-based Instrument Flight Rules ("IFR")/Visual Flight Rules ("VFR") surfaces that factor into the required OCS, which define the allowed limits of aircraft position within the glidepath. The defined surfaces

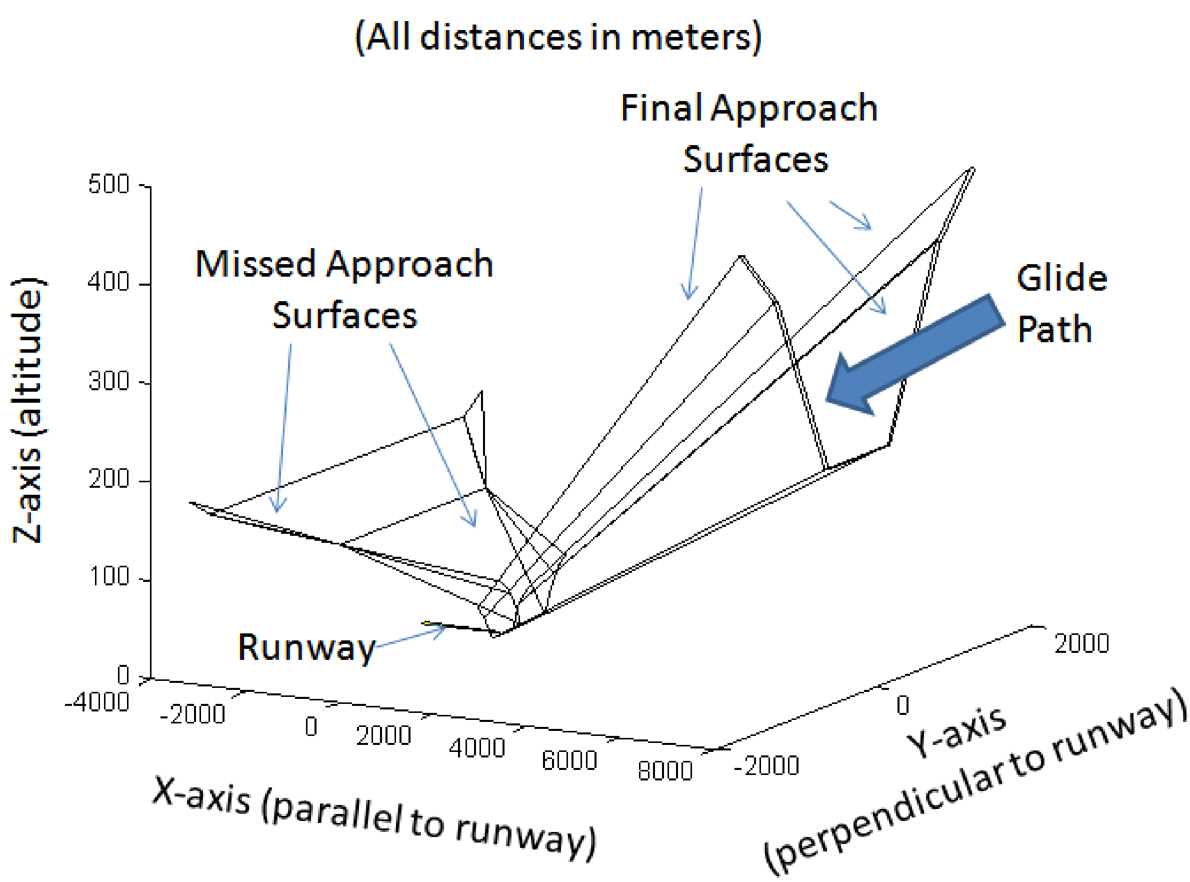
[67] FAA Report [1], at C-11, Proposals for Compatibility for Low Altitude Navigation.

[68] The surface would be simplified to a level that would be acceptable to the FAA as representing a conservative estimate of the glide path in the foreseeable future, even though present obstacles might cause the actual glide path to be further from the proximate base stations.

include: RNAV Final Approach Segments ("FAS"), RNAV Missed Approach Segments, Standard Instrument Departures ("SIDs") using GPS, and Visual Approaches. The surfaces will be determined, at LightSquared's expense, by a professional airspace consulting firm and include case-by-case evaluation and definition of each procedure at a given airport, as well as unique geographic constraints of each airport. The same process can be applied to new and proposed airspace procedures as they are developed.

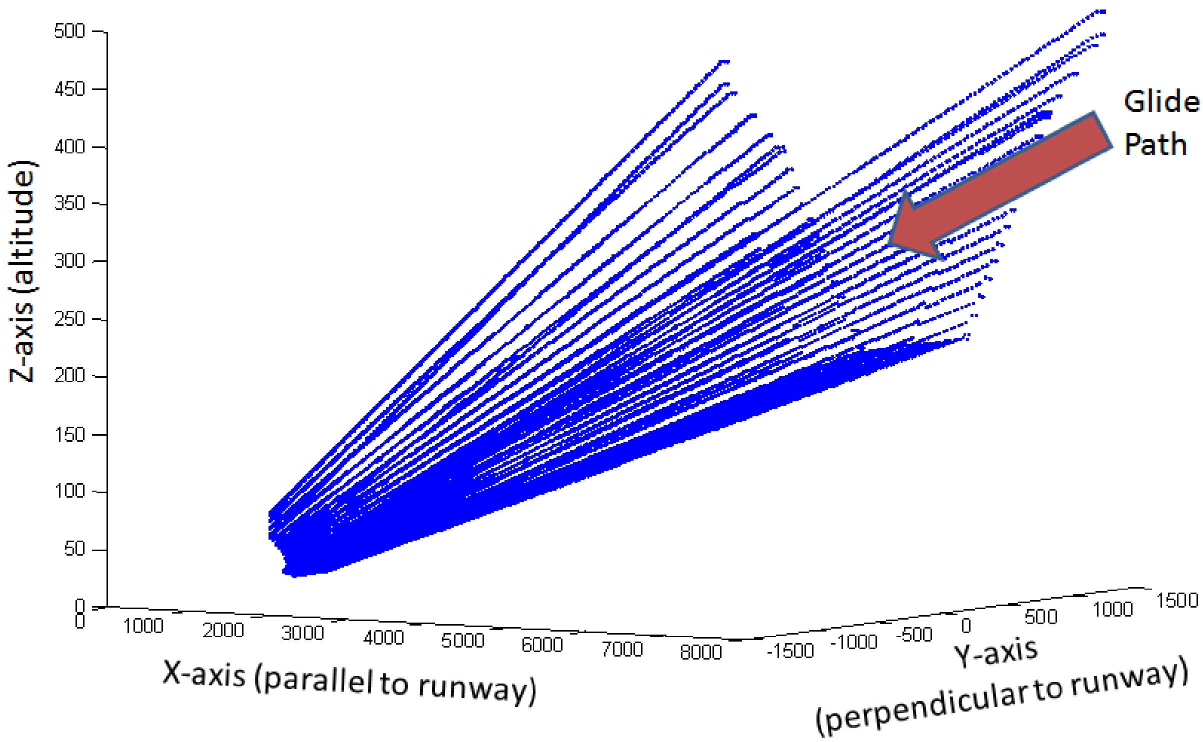
For the DCA study, LightSquared engaged a third-party professional aviation consulting firm to define the relevant surfaces: 43 relevant aeronautical surfaces were defined as 3-dimensional polygons in {lat, lon, and height} coordinates. An example of the surfaces produced for one DCA runway is shown in Figure B.III.1:

**Figure B.III.1 - Example of Aeronautical Surfaces for a Given Runway Approach**




Next, a software program is used to generate closely spaced sample points in 3D-coordinates covering each aeronautical surface polygon. These sample points represent possible aircraft positions at the limits allowed by the aeronautical surfaces. See Figure B.III.2:

**Figure B.III.2: Example of Sample Points Generated for Aeronautical Surfaces**




### 2. Overlaying

The 3-D computer model is next populated with the coordinates of all LightSquared base station antennas within the radio horizon, as supplied from LightSquared's tower database. The base station sector azimuth directions, sector EIRPs, antenna patterns, and antenna down-tilt values are also included in the model. The representative aircraft receive antenna pattern defined by the RTCA study is also incorporated.

At this point, complete geometric information is available to calculate the range, azimuth, and elevation from each base station antenna to each sample point on the aeronautical surfaces. From the azimuth and elevation values, the gains of the base station and aircraft antennas are also determined.

Finally, a common propagation rule set is applied to calculate the received power at each aeronautical surface sample point from each base station sector. The proposed rule set is defined as follows:

1. For base station antenna elevation angles ≥ 6° toward the given aeronautical surface sample point, the propagation path is assumed to be line-of-sight, and the 2-Ray propagation model is applied. The electrical characteristics of the ground (conductivity and permittivity) will be assumed constant but the complex reflection coefficient will be calculated individually for each ray, assuming a split of powers between horizontal and vertical polarization.

2. For base station antenna elevation angles < $6^o$ toward the sample point, the probability $P_{blocked}$ that the direct path is blocked (non-LOS) is estimated. The method used to estimate $P_{blocked}$ is described below. Free-space loss (FSL) is used to calculate the unblocked path loss $PL_{unblocked}$, while the FSL value increased by 15 dB represents the blocked path loss $PL_{blocked}$. The final estimated path loss is the weighted average of blocked and unblocked values:

$$PL\ (dB) = -10\log\left(P_{blocked}10^{-PL_{blocked}/10} + [1 - P_{blocked}]10^{-PL_{unblocked}/10}\right)$$

3. The aggregate received power at each sample point is then calculated as the sum of the individual contributions from each base station sector.

### 3. Blocked/Unblocked Probability Estimation:

In theory, the blocked/unblocked state of each tower-to-sample-point path can be determined precisely using ray tracing methods. An empirical formula for estimating the blockage probability is proposed, using as inputs: (1) the base station antenna elevation angle toward the sample point, and (2) the height of the base station antenna above ground level. These two parameters were chosen because they are readily available in the model, and because, intuitively, one would expect that these factors would strongly influence whether a given path is blocked or unblocked.

For the DCA trial study, the empirical formula for estimating $P_{blocked}$ was derived by evaluating a limited set of ray-tracing scenarios for the Washington DC area, where the aircraft was placed at a number of different altitudes, and the blocked/unblocked state from each tower was precisely determined toward each aircraft position. The individual blocked/unblocked path states are plotted in Figure B.III.3 against the log of the tower-to-sample-point elevation angle on the x-axis, and the log of the tower height above ground level on the y-axis. Log scales were used to facilitate a least-squares approximation to the data. Also a constant value $\alpha$ (= $0.63^o$) was added to the elevation angle values on the x-axis to prevent negative arguments of the log function.

If each blocked (red) point in Figure B.III.3 is assigned a value of 1, and each unblocked (blue) point is given a value of 0, then the distribution of blocked and unblocked points can be modeled by a 2-dimensional least squares approximation, whose value is equal to the estimated blockage probability $P_{blocked}$. Figure B.III.4 shows a contour plot of $P_{blocked}$ using a 4-term least-squares approximation of the form:

$$P_{blocked} = A_1x + A_2y + A_3xy + A_4 \quad (1)$$

where $x$ = log(elev. angle + $\alpha$), $y$ = log(base station antenna height AGL), and coefficients $A_1$ – $A_4$ are determined from the least-squares solution. It was found that the $A_1$ – $A_4$ values determined from the Washington DC data also provided a good blockage approximation when applied to points near the LAKIE (LaGuardia) waypoint, provided that base stations in midtown and downtown Manhattan were excluded. This suggests that it should be possible to derive a small set of least squares approximations having the form of Eq. (1); this general methodology can be applied to a large number of airports in regions sharing a common morphology (suburban, urban, etc.).

**Figure B.III.3 Blocked/Unblocked Path States as a Function of Elevation Angle & Tower Heights (from ray tracing analyses of Washington DC area)**

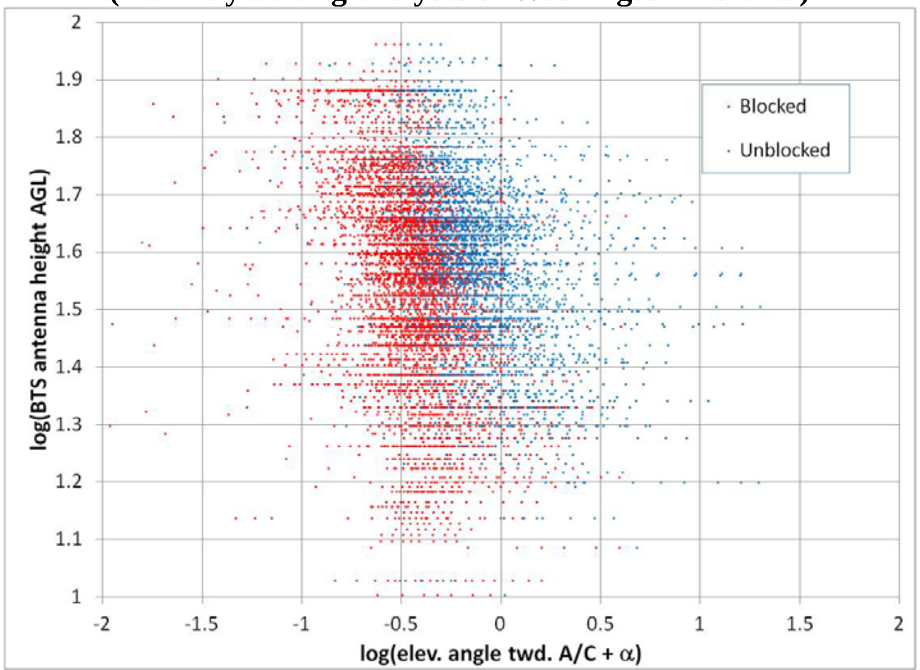
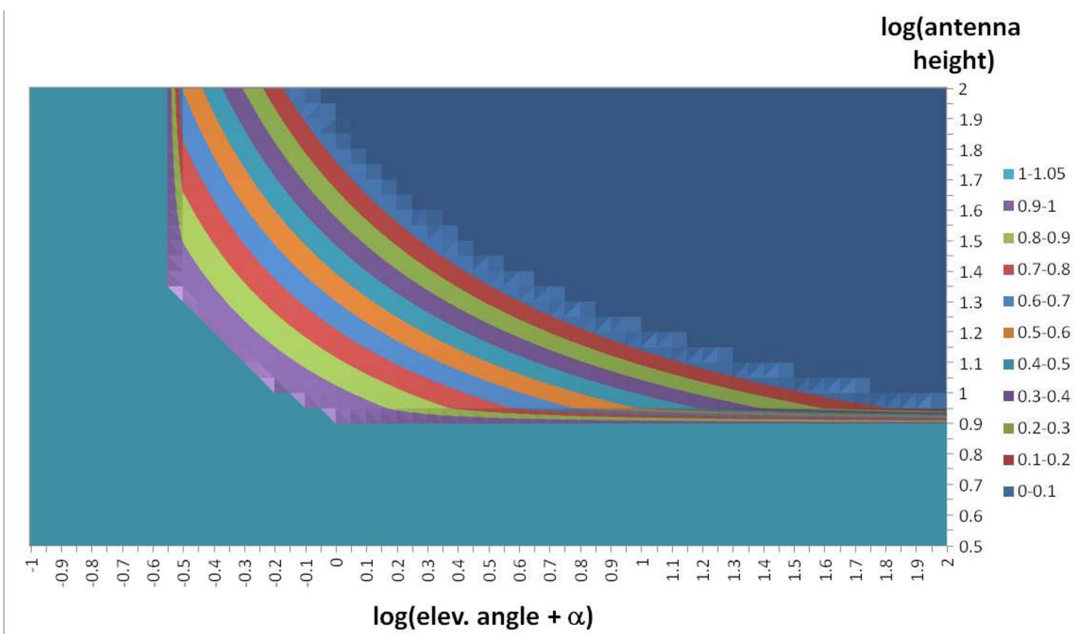


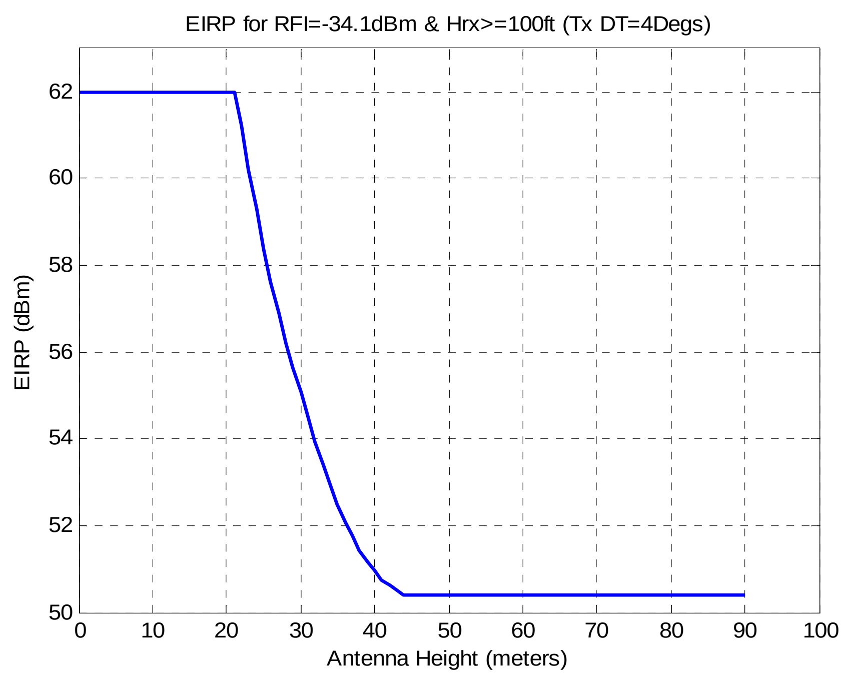

**Figure B.III.4 Contour Plot of Least-Squares Approximation for $P_{blocked}$**



### B. Process for ensuring compliance of aggregate base station emissions for TAWS

In Appendix C of the FAA report,[69] LightSquared's proposals for accommodating the FAA's TAWS evaluation criteria are provided in detail. The FAA's stated TAWS evaluation criteria ultimately came down to ensuring that a *cylinder of exclusion* or "exclusion zone" would exist around each base station antenna whose axis (assumed vertical) would extend from 100 ft above the structure on which the antenna was mounted to 100 ft above ground level; the radius would be 500 ft.[70] LightSquared showed that this cylinder could be created by backing off the base station EIRP according to a schedule of EIRP versus antenna height given in Figure C-4 of the FAA Report and reproduced below as Figure B.III.5.

**Figure B.III.5 EIRP Reduction Schedule for TAWS Accommodation: Free Space Propagation**




The propagation model used in this schedule was free space. The FAA provided several examples of the use of the 2-ray model at low altitudes, but stopped short of proposing a rule of when (under what types of environmental conditions) to use such a model (beyond stating vaguely that the 2-ray model should be used for "low-level operations, close to the ground".[71] This contradicts the position taken by the FAA in discussions during the joint working sessions, where the FAA agreed that if there was significant scattering, the 2-ray model would be

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[69] FAA Report [1], at. C-13, Proposals for Compatibility for Terrain Avoidance Systems.

[70] FAA Report [1], at Section 1.4.

[71] FAA Report [1], at Section 3.1.1.

inapplicable. It also contradicts the FAA's latest Higher Altitude propagation model which uses the 2-ray model in the first segment for aircraft heights up to 535 m.

LightSquared proposed that the use of the 2-ray model be limited to cases of high elevation angle (positive or negative) launch of the transmit signal from the base station antenna. The justifications were: (a) this was articulated in the RTCA Report,[72] and (b) Dr. Parsons has opined in the open literature that such links typically exist for high elevation angles.[73] The FAA never addressed the LightSquared proposal. In the FAA Report, the FAA shows examples of the application of the 2-ray model (for relatively low base station antennas) up to distances exceeding 2 km. It would be quite difficult to find actual scenarios involving low elevation angles that are so devoid of lateral scattering that the 2-ray model would apply.[74] It should be recalled that any lateral scattering greatly reduces the power build up in a 2-ray model for a 10 MHz signal owing to time dispersion. The reason that the power build up occurs *at all* for a 10 MHz signal is that the time dispersion is very small as long as both rays remain in the same propagation plane.

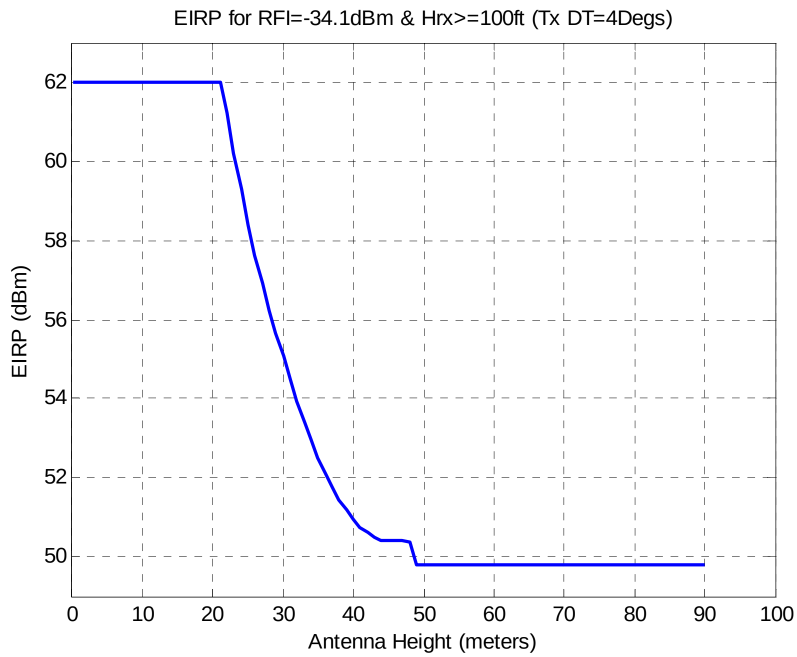
The TAWS power reduction schedule undergoes only a small change when the free space model is replaced by the above mixed (2-ray plus free space) propagation model. The modified schedule is shown below. Note that there is a knee around BTS antenna height of 48 m (154 ft). This is the point that the 2-ray model becomes relevant, where the elevation from the BTS to the aircraft (that is at altitude of 100 ft and lateral distance of 500 ft) becomes more negative than -6 degrees (or |elevation| > 6 degrees).

[72] RTCA Report [3], at B.3.1.1.1. ("This (2-ray) model should be reasonably accurate out to a lateral radius where the direct ray launch angel toward the aircraft antenna is above about 6 degrees. For radii much beyond that point, more complex scattering, blockage, and shadowing effects become significant.")

[73] Rappaport [6], at 120 (states the following regarding the applicability of the 2-ray model "This (two-ray) model has been found to be reasonably accurate for predicting large-scale signal strength over distances of several kilometers for mobile radio systems that use tall towers (heights which exceed 50 m)…")

[74] The presence of lateral scattering would make it unlikely that a 6 dB power build up, as is feasible in the 2-ray model, would occur for a 10 MHz bandwidth base station signal. This is because the time dispersion for typical cellular scattering is known to be around 0.2 to 1.0 microseconds, which leads to a coherent bandwidth that is small relative to the base station signal bandwidth. In contrast, the time dispersion is much smaller for ground reflection from a point in the vertical plane containing both the direct and reflected rays. For example, for transmitter and receiver heights of 30 m, separated by 600 m, the time dispersion between the two rays is 0.01 microseconds.

**Figure B.III.6 EIRP Reduction Schedule for TAWS Accommodation: 2-ray + Free Space Propagation**




We now examine the FAA's position that conformance to such a schedule would be very difficult to administer. This concern is without basis for the following reasons:

- The schedule is completely deterministic and mathematically simple to codify in a spreadsheet. Given a particular base station antenna's height, antenna pattern and downtilt, it is possible to exactly determine the maximum allowed EIRP. There is precedence in previous ATC Orders where an antenna pattern mask was codified into the deployment rules by the FCC. There is similar precedence of specifying a power flux density requirement on the ground, which necessarily includes a dependence on base station antenna height.

- The FAA has cited (and the NTIA reiterated) a need to "constantly monitor" the EIRP levels. The reason for this is unclear, unless the FAA is concerned that LightSquared would surreptitiously change the EIRP levels. LightSquared, in a letter to the FAA, has sought to assuage such concerns by offering to put the oversight of the base station settings under a trusted third party, at LightSquared's sole expense.[75]

- The channel is time invariant, therefore the exclusion cylinder is also time invariant. The power levels on the surface of the cylinder cannot change autonomously.

[75] Letter from Sanjiv Ahuja, Chairman and CEO, LightSquared, to Ray LaHood, Secretary of Transportation (Dec. 18, 2011) [10].

- There is no dependence in the propagation model of a particular environmental morphology. New structures around the base station antenna do not change the propagation model.

In summary, the TAWS power reduction schedule is simple to codify and administer. Beyond vague assertions about complexity, the FAA has never offered any specific reasons as to substantiate its concerns.

**References**

[1] FAA Status Report: Assessment Of Compatibility Of Planned LightSquared Ancillary Terrestrial Component Transmissions in the 1526-1536 MHz Band with Certified Aviation GPS Receivers (Jan. 26, 2012): http://apps.fcc.gov/ecfs/document/view;jsessionid=yBJtP9QcT47tjYzQh3JyV14WQLxG3DZ24xkQpYJbRrKWRWbPrjbC!-321460796!1471562840?id=7021860338

[2] Letter from Lawrence Strickling, Administrator, National Telecommunications and Information Administration, to Julius Genachowski, Chairman, Federal Communications Commission (Feb. 14, 2012).

[3] RTCA Report: Assessment of the LightSquared Ancillary Terrestrial Component Radio Frequency Interference Impact on GNSS L1 Band Airborne Receiver Operations, DO-327 (June 3, 2011).

[4] Clarke, R. H., "A Statistical Theory of Mobile-Radio Reception," 47 Bell Systems Technical Journal 6, pp.957-1000 (1968).

[5] Parsons J. D., The Mobile Radio Propagation Channel (2 Ed.), John Wiley and Sons, Chichester, UK, 2000.

[6] Rappaport, T. D., Wireless Communications Principles and Practice (2 Ed.), Prentice Hall, 2002.

[7] Fizzle Technologies, "The LightSquared Comments on the use of the Hata Propagation Model," (Sept. 11, 2011).

[8] Loo, C., "A Statistical Model for a Land Mobile Satellite Link," *IEEE Transactions on Vehicular Technology* Vol. 34, No. 3 (Aug. 1985). Copyright © 1985 IEEE

[9] J. Goldhirsh and W.J. Vogel, *Propagation Handbook For Land-Mobile-Satellite Systems*, Report SIR-91U-012, Johns Hopkins University Applied Physics Laboratory at Chap 11 (April 1991).

[10] Letter from Sanjiv Ahuja, Chairman and CEO, LightSquared, to Ray LaHood, Secretary of Transportation (Dec. 18, 2011).

[11] Parsons, J. D. and Gardiner, J. G., Mobile Communication Systems, Blackie & Sons Ltd., 1989.

**DECLARATION OF JOHN DAVID PARSONS**

I, John David Parsons, make the following declaration in connection with my review of the Letter from Lawrence E. Strickling, Assistant Secretary for Communications and Information, U.S. Dep't of Commerce, to Julius Genachowski, Chairman, FCC (dated Feb. 14, 2012) ("NTIA Letter") and the U. S. Department Of Transportation Federal Aviation Administration Status Report: Assessment Of Compatibility Of Planned LightSquared Ancillary Terrestrial Component Transmissions In The 1526-1536 MHz and With Certified Aviation GPS Receivers (Jan 25, 2012) ("FAA Report").

1. I am an Emeritus Professor and Honorary Senior Fellow at the University of Liverpool. I held the David Jardine Chair of Electronic Engineering from 1982 until 1998. During this period I was, at various times, Chairman and Head of the Department of Electrical Engineering and Electronics, Dean of the Faculty of Engineering and Pro-Vice Chancellor (Vice-President) of the University. I received a B.Sc. degree in Electrical Engineering (Magna cum Laude) from the University of Wales in 1959, an M.Sc. in Electronics from the University of London in 1967 and a D.Sc. in Electronic Engineering (Radiocommunications) from the University of London in 1985. I also hold the following certifications; FREng, (Fellow of the Royal Academy of Engineering, London) FIET, (Fellow of the Institution of Engineering and Technology – formerly the Institution of Electrical Engineers, London) and SMIEEE (Senior Member of the Institute of Electronics and Electrical Engineers, New York).

2. In addition to my teaching experience, I have conducted extensive research on various aspects of radio engineering, specializing in radio propagation and radio channel characterization particularly in connection with cellular systems, and have published approximately 150 technical papers in peer-reviewed Journals and at major conferences. I have also authored or co-authored 3 books on the topics of radio propagation and radio engineering. I have acted as a consultant to several companies and have given evidence as an expert witness in Courts of Law. A copy of my CV is attached to this Declaration.

3. I previously reviewed a draft of the FAA Report and provided my opinion on the validity of the FAA's propagation model described therein, a copy of which is attached to Appendix C of the FAA Report. I was recently asked by LightSquared to review a propagation model authored by the FAA and described in Appendix B of the draft FAA Report dated January 13, 2012, for determining the compatibility between LightSquared's terrestrial system and FAA GPS requirements. Based on this review I authored an Opinion titled, "Review of Appendix B in the FAA Status Report dated 13th January, 2012."

4. A copy of my professional assessment is attached hereto.

I declare under penalty of perjury under the laws of the United States of America that the foregoing Declaration is true and correct.

Executed on February 29th, 2012.

J.D. Parsons.

John David Parsons

# Review of Appendix B in the FAA Status Report dated 13th January 2012

## 1 Background

In its Status Report [1] (the report), the FAA presents Section 3 as "Analysis Methods and Results", comprised of the following sub-sections:

- 3.1 Path Loss Models;
- 3.1.1 Deterministic Models;
- 3.1.2 Probabilistic Models;
- 3.1.2.1 Probabilistic Model Background; and
- 3.1.2.2 General "Extended Suzuki" Model Scenario Dependent Parameters.

During a telephonic meeting held on 4th January 2012, LightSquared reviewed the content of a draft version of the report with the FAA and requested the FAA to provide additional information regarding the propagation models it had used in the sections listed above. This information was to include: theoretical and physical descriptions of the models; an explanation of how the parameter values used in the models should be determined; and a justification for the selection of the so-called breakpoints which determine the boundaries between the segments of the multi-segment model. LightSquared also asked the FAA to provide examples illustrating the application of the model and the determination of the breakpoints.

The final version of the report, dated 13th January 2012, contains an appendix (the appendix) which was not included in previous versions of the report and presumably was provided in response to the request described above.

This paper reviews the appendix and presents an opinion of same.

# 2 Discussion

With regard to the appendix, this paper analyses the models presented and compares them with established methods and practices, assesses the clarity of presentation, and discusses the process proposed by the FAA for selecting breakpoints and optimizing parameters suitable for use in the models presented in the their report.

## 2.1 Determination of Median Isotropic Path Loss Segment Break Points

In section 3.1.2.2 of the report, the so-called "extended Suzuki" model is introduced. The range from the aircraft nadir to the ATCt cell tower is split into four segments for modelling purposes and the method of determining the break points ($r_1$, $r_2$ and $r_3$) between these segments is explained. For completeness the following is an extract from the report:

> "...the median path loss break points are determined by the following guidelines (see RTCA DO-327, Appendix B [2]):

- At short ranges a two-ray median path loss model is used up to the range $r_1$ where the vertically polarized component reflection coefficient is at minimum magnitude. This break point varies with aircraft antenna height.
- Beyond the median path loss is extended in a continuous manner proportional to $r^{-2}$ to the range $r_2$ which is generally around 2 km depending on the local terrain and cell tower heights. As the aircraft antenna height increases, $r_1$ approaches $r_2$. Once these break points get within a few hundred meters of each other, $r_2$ is set equal to $r_1$ and the second path loss segment is eliminated. This is the case at aircraft heights approaching 535 meters as in the final approach fix Waypoint scenario (see Section 3.2). From $r_2$ to the point $r_3$ where line of sight blockage becomes significant as determined for the specific site, median path loss is proportional to $r^{-\Gamma}$. The point $r_3$ varies proportionally with aircraft antenna height out to a maximum of 20 km at an aircraft antenna height of 535 meters. The parameter $\Gamma$ is selected to provide continuity in path loss. At aircraft antenna heights slightly beyond 535 meters, the exponent $\Gamma$ approaches 2 and the entire path loss model becomes deterministic (free space path loss). The

remaining “extended Suzuki” parameters are set to values that reflect this change ($\psi_o(r) = 0$, $\rho^2(r) = 1$, $\sigma(r) = 0$).

- Beyond $r_3$ the Hata-Okumura suburban median path loss model is used

  Once these break points are known, the remaining “extended Suzuki” parameters $\psi_o(r)$ *and* $\rho^2(r)$, and $\sigma(r)$ can be determined. For the shorter ranges, $0 \leq r < r_2$, the line-of-sight parameter $\rho^2(r)$ will be unity while the Rayleigh parameter $k\psi_o(r)$ will conservatively be 10 dB lower. At $r_3$ and beyond, there will be increasingly heavy blockage of the line-of-sight component with all of the power resulting from scattering (Rayleigh component). In between these two break points it is reasonable to assume both parameters $k\psi_o(r)$ and $\rho^2(r)$ change linearly with distance.”

It is worth pointing out that prior to the issue of the FAA report, both LightSquared and its external consultants were under the impression that a 3-segment model with fixed break points was being used. Now it appears that the proposal is to use a 4-segment model with variable breakpoints.

## 2.2 Two-Ray Isotropic Path Loss Model (B.1)

This section gives some background information on the calculation of path loss for the situation depicted in Figure B-1 of the appendix. After correctly stating the equations for the reflection coefficient of real ground, the so-called complex field factor is defined and contains the quotient $R_{DIR}(r)$ / $R_{REF}(r)$. Simple derivation shows that this quotient should be squared and therefore, as it stands in the appendix, is incorrect. The equations for the vertically- and horizontally-polarized complex field factors should be:

$$P_v(r) = 1 + \left[ \rho_v(r) \cdot \left( \frac{R_{DIR}(r)}{R_{REF}(r)} \right)^2 \cdot \exp(-j\phi(r)) \right] \quad (1)$$

$$P_h(r) = 1 + \left[ \rho_h(r) \cdot \left( \frac{R_{DIR}(r)}{R_{REF}(r)} \right)^2 \cdot \exp(-j\phi(r)) \right] \quad (2)$$

If the correction is assumed, then equations (B-1) and (B-2), which are correct, are easily derived.

The equations (B-1) and (B-2) allow determination of the path loss between isotropic antennas located at the points shown in Figure B-1. In practice however, it is essential to know the polar patterns of the transmit and receive antennas to make any meaningful calculations [3]. For given values of $h_A$, $h_E$ and r, the lengths of the direct and reflected paths can be determined as can the angle θ and hence the reflection coefficient. If the radiation patterns of the antennas are also known, then the antenna gain in the direction of interest can be found and the path loss can be calculated. In practice, the location and height of the transmit antenna is fixed but as the aircraft moves along its flight path, hA and r change and so also do the other variables mentioned above. To get a full picture, incremental calculations therefore have to be made at intervals along the flight path using the appropriate values of the various parameters.

## 2.3 Hata-Okumura Median Isotropic Path Loss Model (B.2)

This section gives some background to the Hata-Okumura [4, 5, 6, 7] path loss model. The treatment is slightly different from that in Appendix B of ref [2] in that some parameters are defined slightly differently, but the resulting process is essentially the same. The factor α gives the path loss for distances less than 20 km in terms of Hata's formulation for urban areas in quasi-smooth terrain. The expression for the antenna factor AF($h_A$, $h_E$) contains terms *Max*($h_A$ , $h_E$) and *Min*($h_A$ $h_E$) which presumably mean respectively, the greater and smaller of $h_A$ or $h_E$. This is a reasonable interpretation of Hata's formulation (in which the base station antenna is assumed to be the higher of the two antennas) but this is not specifically stated here or indeed, explained or justified. The path loss is expressed by equation (B-3).

It now seems relevant to examine whether this RTCA equation is being used within the range of applicability of the model. The original Hata model was specified as follows:

- f: 150 – 1500 MHz
- $h_{Base}$: 30 – 300 m
- $h_{Mob}$: 1 – 10 m
- r: 1 – 20 km

The RCTA model includes the ITU-R extension for lateral separations more than 20 km so distance is not an issue. Neither is the height of the higher antenna (normally the aircraft antenna in this case). However, the FAA has declined to use the COST 231 version of the Hata model which specifically extends its frequency range to 2000 MHz so the model as it stands is being used marginally outside its specified range in this respect. However, perhaps more important is the height of the lower antenna which in the present application is very often significantly higher than the maximum specified value of 10m. This is a matter of some concern as the antenna factor has a significant impact when calculating path loss.

The authors have also pointed out [8], an anomaly in the RTCA formulation of the Hata equations, which is also present in the document under review. Specifically, the essential difference between the original Hata and the current RTCA formulations is the expression used for the mobile (the lower of the two antennas, analogous here to $h_E$) antenna factor. Hata's formulation is basically for small/medium sized cities while the RTCA expression uses the value of mobile antenna factor applicable for frequencies above 400 MHz in a large city—despite the fact that the RTCA report states that suburban parameters are appropriate for the environment surrounding an airport. It appears that the RTCA report is anomalous in this respect and that there has been an arbitrary choice of parameters based on criteria which are unknown to the current authors. The reason for using the "large city" value remains unexplained.

## 2.4 Break Point Determination (B.3)

For each of the four segments of its multi-segment model, the FAA document provides a separate sub-section in which the determination of the breakpoint distance is defined. Each sub-section is therefore reviewed here in the order in which they appear. Before reviewing each sub-section in turn, it should be noted that the FAA appendix lacks any form of description or explanation regarding the physical rationale used for the determination of the break points and that only mathematical criteria, seemingly removed from practical considerations, are presented.

### 2.4.1 Determination of the First Break Point $r_1$ (B.3.1)

The extract from the report quoted above (Section 2.1), teaches that the first break point is set to occur near the lateral range at which the magnitude of the vertical polarization reflection coefficient $\rho_v$ is a minimum. In other words it is set at a distance corresponding to the Brewster angle, which for the electrical parameters given in the example ($\sigma$ = 0.15 S/m, $\varepsilon_r$= 7, f = 1531 MHz) is close to 20° as Figure 1 shows. For the heights given in the example, ($h_A$ = 76 m, $h_E$ =

41 m), $r_{min}$, is stated to be 313.475 m. These figures seem to fit with Figure 2 and show that ψ (the angle of incidence) is about 20° at a lateral distance of approximately 320 m.

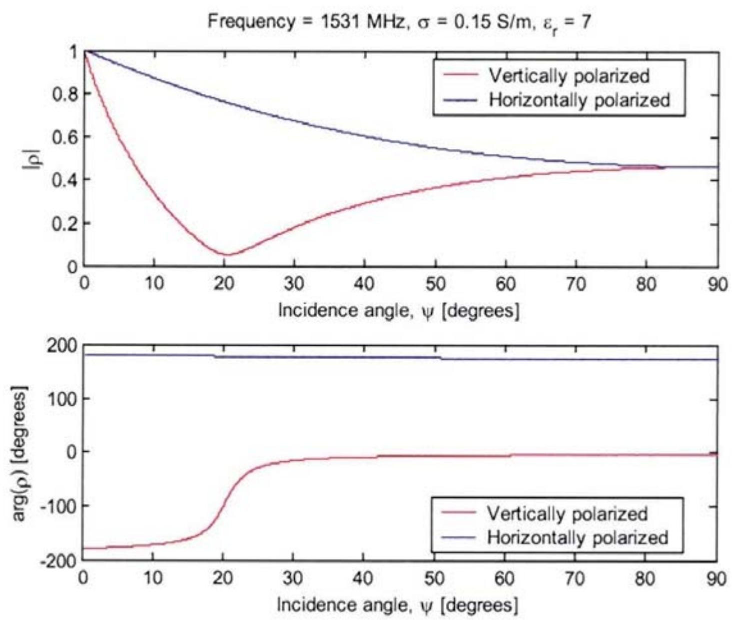



Figure 1: The magnitude and phase of the reflection coefficient at 1531 MHz, for vertically- and horizontally-polarized waves. Electrical parameters for ground used in the FAA appendix have been applied.

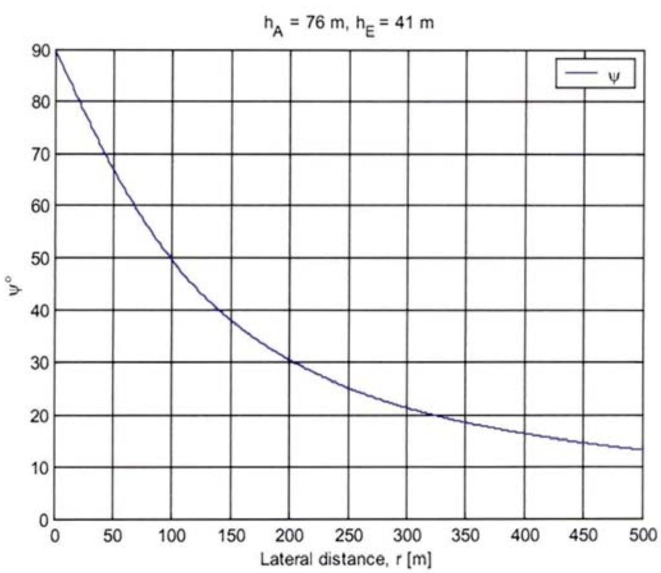



Figure 2: The angle of incidence (ψ) plotted as a function of the lateral distance using antenna height values presented in the FAA appendix.

The appendix then states: "In other words, $r_1$ is the radial point close to $r_{min}$ at which the 2-Ray horizontal and vertical polarization path losses are equal". It is not immediately obvious that this is the case, but the authors have made the necessary calculations and can verify the accuracy of this statement. If $h_A$ = 76 m and $h_E$ = 41 m, then for a concrete reflecting surface, $r_{min}$ is c.313 m.

We also point out here that the choice of this criterion for establishing the first break point is not explained—it seems arbitrary and has not been justified.

### 2.4.2 Determination of the Second Break Point $r_2$ (B.3.2)

This section of the appendix allows for the possibility that this segment may be eliminated. It exists only if a line-of sight (LOS) path is apparent. If $r_1$ is large, then it may not exist and $r_2$ is then set equal to $r_1$. However, if this segment does exist, then free space propagation conditions exist within it and the path loss is independent of polarization. The segment is more likely to exist if $r_1$ is small and the aircraft is still at a low height for distances greater than $r_1$. Determination of $r_2$ has to be done for each site and depends on whether the cell towers up to a range of $r_2$ have a LOS path to the aircraft or not. The appendix contains no comment on what might constitute a sufficient percentage of cell sites. It is clear that some kind of morphological data base has to be used to determine $r_2$.

In addition to this section supposedly describing the determination of the second breakpoint, a path loss equation is presented, devoid of both explanation and justification. The equation, reproduced here for convenience, $PL_{segmenr2}(r) = PL_{2RV}(r_1)(r / r_1)^{-2}$, is a function of the lateral distance r and comprises the product of two components—a constant, determined to be the path loss at the $r_1/r_2$ boundary; and a quotient. The latter component seems to be anomalous for two reasons. Firstly, the quotient is a function of r which we assume to be the same r throughout the appendix and as such should be expressed in conjunction with the previous breakpoint for example as $(r - r_1)$. Secondly, the quotient is raised to the negative power of two which is contrary to the square law proportionality of free-space propagation path loss.

As a final comment on this sub-section, the authors wish to draw attention to the statement "the path loss exponent for the following segment ($r_2$ to $r_3$) is computed to be very near 2". This may well be the case, but no evidence has been provided to substantiate or support it. Input documents on free space models and the path loss exponent [10, 11] are available and refer to this type of situation. It is also worth posing the question again, about an appropriate value of standard deviation to associate with a segment in which the exponent is close to two.

### 2.4.3 Determination of the Third Break Point $r_3$ (B.3.3)

The procedure for determining $r_3$ is more complex than for $r_1$ or $r_2$. It starts with an evaluation of the distance at which a majority of towers appear to be obscured, assuming their heights to be 30 m (100 ft)—it is stated that this can be done by on-site inspection or by using available software tools and is typically around 5 km. This minimum distance is denoted by $r_{3min}$.

Having determined $r_{3min}$, the appendix defines some additional parameters and describes a procedure for calculating $r_3$ and the path loss for locations in this sector. If the aircraft height is outside the range specified in the equation that defines $r_3$ then there are no segments and the path loss is the free-space value. At the end of this section it is stated that the associated median path loss for the segment from $r_2$ to $r_3$ is given by $PL(r) = \psi_2 (r_2)(r / r_2)^{-r}$. Again we observe that -Γ, Γ being as defined in the document, is used rather than +Γ. This is believed to be incorrect as it implies that the path loss decreases as the distance is increased. The median path loss for ranges greater than $r_3$ and out to $R_o$ (the radio horizon) is given by the following equation: $PL_{Hata}(r) = \mathrm{Exp}[-\alpha](r / 1000)^{-\beta(r)}$. So there is a segment $r_2$ to $r_3$ and a final segment from $r_3$ out to $R_o$.

This section of the appendix does not discuss the extended Suzuki model [12, 13, 14] *per se* but it would appear that the determination of the third breakpoint is used in connection with this. This has been noted, and in this context we comment that the appendix does not teach how to determine the appropriate parameter values for use in the extended Suzuki model.

Finally in this section we point out that in the latest version of the appendix, the equation defining $r_3$ contains the factor Exp(– α) whereas in the previous version it was Exp(α). We assume that this is just the correction of a typographical error.

### 2.4.4 Determination of the Fourth Break Point $r_4$ (B.3.4)

In this section it is stated that $r_4$ is not a break point that is concerned with defining path loss segments, but is needed in order to define the standard deviation associated with the log-normal component of the fading signal. The standard deviation is initially defined in terms of a number of step functions; however it seems that there is an omission and that the equation should read $\sigma_{dB}(r) = 6.4$ dB, $r_3 \leq r < r_4$. The text then goes on to explain how this series of step functions is approximated by a fifth-order polynomial and $r_4$ is defined as the value of r in the range $r_{3min}$ to $R_o$

at which the value of the polynomial is 6.4 dB. The importance of r4 is not clear and neither is it clear what value of standard deviation should be used for distances greater than $r_4$.

## 2.5 Breakpoint determination

We do not see any explanation in the appendix for the choice of break points—physical and engineering criteria are not mentioned and the choice of values seems to have been determined purely by mathematical criteria or to ensure smooth transitions between the various regions of the multi-segment model.

# 3 Opinion

Overall our opinion is that this appendix is terse and cumbersome. It is very difficult to unravel some of the equations particularly those in section B.3.3 since no indication is given of the logic behind the approach that has been taken. We have come across a considerable number of anomalies, inaccuracies and widespread illogic. Although we have succeeded in resolving many matters, some of them being mentioned in the body of this paper, certain questions remain unanswered. For example it appears that:

1. In section B.1 the equations given for the complex field factors $P_v(r)$ *and* $P_h(r)$ are incorrect and the correct equations have been quoted as equations (1) and (2) in section 2.2 above. Equations (B-1) and (B-2) in section B.1 of the appendix are correct, but it is not clear whether the FAA calculations of path loss using these equations were made using the correct or incorrect vales of $P_v(r)$ *and* $P_h(r)$.

2. In section B.3.1, two criteria are quoted for determining $r_1$: first the distance at which the magnitude of the reflection coefficient for vertical polarization is a minimum and secondly the distance at which the path losses for vertical and horizontal polarization are equal. Neither is it explained nor is it immediately obvious that these amount to the same thing; but calculations by the authors confirm that they do.

3. The in-line equation in section B.3.2 implies that the path loss is inversely proportional to the value of $r_2$ whereas it is actually directly proportional to $(\text{range})^2$. Further, the square law proportionality only starts at $r_1$ so the distance involved would appear to be $(r - r_1)$ not r.

4. A problem similar to that described above occurs in section B.3.3 in connection with $r/r_2$.

5. From section B.3.3 it would appear that there are 4 segments, 0 to $r_1$, $r_1$ to $r_2$, $r_2$ to $r_3$ and $r_3$ to $R_o$ and that different path loss equations apply in these segments. However the values of standard deviation given in section B.3.4 do not correspond with these limits. The distance $(r_2 + r_3)/2$ is introduced without any explanation and as has been pointed out above, there appears to be an omission in the final definition relating to the 6.4 dB value of standard deviation. Further, the importance and relevance of $r_4$ is not clear, and neither is it clear what value of standard deviation is to be used for distances greater than $r_4$ although it is tempting to surmise that it is the value given by the polynomial.

The main part of the report gives the impression that the extended Suzuki model is applied in all segments with different parameters appropriate to the conditions existing in that segment. From the appendix it seems that this is not the case—there are four segments that use respectively the 2-ray model, the free space model, the extended Suzuki model and the RTCA version of the Hata-Okumura model. It is not clear whether steps are taken to ensure continuity at the break points, but, in any case, we have previously argued that this is an artificial condition.

Finally we would wish to reinforce our point made earlier, that the appendix is poorly written; contains unwieldy mathematical equations; is devoid of useful description and lacks clarity. It contains several anomalies; is somewhat inconsistent and illogical, and does not serve the purpose expected of a technical appendix, namely to support text that appears in the main document by providing clarification.

# 4 References

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3. Leather, P.S.H., and Parsons, J.D., "On the applicability of the 2-ray path loss model to LightSquared scenarios", (input document submitted to LightSquared), *Fizzle Technologies Limited*, 15th December 2011.

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5. Okumura, Y. Ohmori, E. Kawano, T. and Fukuda, K., "Field strength and its variability in the VHF and UHF land mobile radio service", Rev. Elec. Comm. Lab., Vol 16, No. 9/10, pp. 825-873, 1968.

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13. Leather, P.S.H., and Parsons, J.D., "Review of the extended Suzuki model presented in the FAA draft Final Report dated 23rd December 2011", (input document submitted to LightSquared), *Fizzle Technologies Limited*, 2nd January 2012.

14. Patzold, M., Killat, U., and Laue, F., "An Extended Suzuki Model for Land Mobile Satellite Channels and its Statistical Properties" *IEEE Trans on Vehicular Technology Vol. 47, No. 2*, pp. 617—630, May 1998.

*CURRICULUM VITAE*

# PROFESSOR DAVID PARSONS

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## ACADEMIC AND PROFESSIONAL QUALIFICATIONS

1959 B.Sc., Electrical Engineering (Magna cum laude), University of Wales
1967 M.Sc. (Eng.) Electronics, Kings College, London
1985 D.Sc. (Eng.) University of London
Chartered Electrical Engineer
Fellow, Institution of Engineering and Technology (formerly the Institution of Electrical Engineers) (FIET)
Senior Member, Institute of Electrical and Electronic Engineers (SMIEEE)

## HONOURS

1988 Fellow, Royal Academy of Engineering (FREng.)

## CURRENT STATUS

Retired. Emeritus Professor at the University of Liverpool
Honorary Senior Fellow

## CAREER

1982 - 98 Professor of Electrical Engineering, University of Liverpool (Holder of the David Jardine Chair)

1983 - 86 and 1996 - 98
Head, Department of Electrical Engineering and Electronics

1986 - 1989 Dean, Faculty of Engineering
1990 - 1996 Pro Vice Chancellor

1969 - 82 University of Birmingham, Department of Electronic and Electrical Engineering;
1969 Lecturer, 1977 Senior Lecturer
1982 Reader in Radiocommunications

1966 - 68 City of Birmingham Polytechnic (now University of Central England), Principal Lecturer in Electronic Engineering.

| | |
|---|---|
| 1962 - 66 | The Polytechnic, Regent Street, London, (now University of Westminster). |
| 1959 - 62 | GEC Ltd., Applied Electronics Laboratories, Stanmore, Middlesex, Research and Development Engineer. |

## OTHER ACTIVITIES

| | |
|---|---|
| 1977 | United Nations Expert at the International Telecommunications Training Centre, New Delhi, India. |
| 1978 - 82 | Honorary Senior Principal Scientific Officer, Royal Signals and Radar Establishment (RSRE), Malvern. |
| 1982 | Visiting Professor in Electronic Engineering, University of Auckland, New Zealand. |
| 1987 | Visiting Research Engineer, NTT Radio Communication Network Laboratories, Yokosuka, Japan. |
| 1996 | Member, HEFCE National Panel for Electrical Engineering, Research Assessment Exercise |

Member of several IEE Committees and Boards.
Chairman IEE Professional Group E8 (Radiocommunication Systems), 1985-88.
IEE Council 1988-89.
Chairman, Mersey and North Wales Centre 1989-90.
Presented IEE Christmas Lecture 1992.
Advisor and Consultant to several industrial companies.

## TECHNICAL AND RESEARCH EXPERIENCE

My major technical interest is in the field of telecommunications and my involvement spans a period of over 45 years. Within that general field I have been principally interested in radio communication systems although I have always kept up to date with developments in telephone, television and cable systems. I am familiar with the principles and practical techniques used in analogue and digital radio systems in all frequency bands and have extensive knowledge and experience of first and second generation cellular radiotelephone systems.

As far as research is concerned I have wide interests but have specialised in tackling the problems of mobile, cellular and personal communication systems. A major theme of this research has been the characterisation of the radiocommunication channel; it has encompassed studies of propagation in urban areas and within buildings, man-made electrical noise, digital radio systems and channel simulation. I have also been actively involved in the development of radio system techniques, such as diversity reception, which can be used to mitigate the deleterious effects caused by the radio propagation channel. This research attracted considerable financial support. I always maintained a group of active research workers and during my career more than 30 successful Ph.D. theses were submitted by students who worked under my supervision.
I have given many invited lectures, seminars and overview addresses.

## CONSULTANCY

For many years I have been active as a radio and telecommunications consultant to industrial and government organisations. I have also written several reports in connection with cases of litigation and appeared as an expert witness in court cases. In 1988 I gave evidence before a Select Committee in the House of Lords.

Organisations which have sought my advice include:-

Air Call Ltd.
Cellnet
DTI (Radiocommunications Agency)
Ericsson Radio Systems AB
Government of the Isle of Man
Hutchison Microtel
London Fire and Civil Defence Authority
London Underground Ltd.
Mercury Personal Communications
Metropolitan Police
Racal Research Ltd.
Sinclair Communications
Mobile Systems International plc
Wragge and Co (Solicitors) Birmingham
Louis Berkson and Globe (Solicitors) Liverpool

## PUBLICATIONS

Books

"The Mobile Radio Propagation Channel", John Wiley, 1992.(second edition , 2000)

"Mobile Communication Systems", (with J. G. Gardiner), Blackie and Sons, 1988.

"Electronic and Switching Circuits", (with S. M. Bozic and R. Cheng), Edward Arnold, 1975.

Contributions to several other books.

Over 100 papers published in international professional engineering journals.

4 "best paper"(premium) awards from the IEE for published papers in 1975, 1982, 1983 and 1992.

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COMMERCIAL IN CONFIDENCE

# The LightSquared Comments on the use of the Hata Propagation model

Ajay Parikh (LightSquared) has written a very good commentary on the matters under debate [Appendix A], matters which have only been partially answered by the input from Bob Erlandson (RTCA) [Appendix B]. We will review Appendix A and Appendix B sequentially as follows.

## 1 Discussion of appendix A

### 1.1 Introductory paragraph

We agree entirely with the introductory paragraph in which the reasons behind the development of the COST231-Hata model are explained. This is also our understanding of the history of the development of the COST231-Hata model.

### 1.2 List item number 1

Ajay is correct in his statement that in the two relevant equations, only the first two terms differ. It is quite important to emphasise this, because it means that the dependence on other factors such as antenna heights, and distance remain the same. Moreover apart from the extension of frequency range to 2000MHz, the restrictions on the other parameters remain the same as in the original model. This being the case, we do not see why the correction factors available for the original model should not be applied to the COST 231 model.

Ajay has provided numerical values for the path loss attributed to the first two terms in the equation. We agree with his calculations. However we would like to add two further minor points: If the same calculations are made at 1500MHz the following results are obtained; Hata 152.64dB and COST231 153.96dB showing that at the "limit" frequency the two equations give values which are within 1.32dB. Further, at 2000MHz, the figures are; Hata 155.9dB, COST 158.2dB. So as expected the COST model predicts higher losses in the frequency range 1500 - 2000MHz, the difference at 2000MHz being 2.3dB. This analysis demonstrates in numerical terms, the reason that HATA model was extended by COST231.

## 1.3 List item number 2

Ajay makes a good point here. If it is sensible to use the "large city" antenna height expression, then to be consistent with this we should not apply the suburban correction factor to the environment. To "mix and match" like this is not good engineering practice and casts doubts on the robustness of the model - it could be construed as a licence to choose whatever parameters are necessary to make the model fit a certain data set. In any case, while it could be argued that the environment in the immediate vicinity of the airport is suburban (airports often consist of a number of isolated terminal buildings surrounded by large open areas for runways etc) , it could also be argued that in practice we are concerned with the overall environment over a much larger area.

## 1.4 List items number 3 and 4

Again inconsistencies are pointed out which have remained unanswered by Bob Erlandson. We have not checked the figures for the aggregated RFI path loss, but as far as we are aware, there is no propagation mechanism in this scenario that could result in a path loss less than would be predicted by the free-space equation. This seems to be a major weakness in the overall prediction model.

## 1.5 List item number 5

Bob Erlandson has answered this by sending an extract from a paper that is under peer review. On the assumption that the mathematics is correct (and we have not yet studied it in sufficient detail to think otherwise) it does seem that the STD of the individual path losses plays an important part. What we are lacking is any "feel" for why this is the case. We believe the mathematics but, as engineers, we like to have an intuitive feel that makes us comfortable with the analysis. We don't have that yet and a few sentences of explanation would be useful.

# 2 Discussion of Appendix B

## 2.1 Introductory paragraph

Bob Erlandson confirms his belief that the original Hata model is the most appropriate in the given situation.

## 2.2 List item number 1

Continuing from his introductory assertion, he says that his basic reason is because it is "a closer upper bound to actual median path loss measurements in our representative airport environment than COST231". We are uncertain about the meaning of this phrase. Is practical measurement data available, and has LightSquared seen it? Does it confirm his assertion?

Erlandson seems to place great emphasis on the comment in Parsons ("The Mobile Radio Propagation Channel") so perhaps that should be clarified. The comment is meant to imply that from measurements reported in the literature, it seems that areas that the Japanese would classify as suburban may be on the whole, somewhat more built up than areas regarded as suburban in the USA. There is no comment in the book about city centres. Downtown Tokyo is very heavily built up, but so is downtown Los Angeles, New York and many other US cities. We believe that they should all be regarded as essentially similar.

## 2.3 List item number 2

It all depends on what one is prepared to consider as "good agreement". We think that the agreement between the COST231-Hata model and the Okumura tables is equally good.

# 3 Summary

In summary we believe that the case that has been advanced for using the original Hata model , particularly with the "suburban" correction factor is far from conclusive and that Bob Erlandson should be asked for further comments particularly on the inconsistency between the correction factors applied for the environment and the antenna height factor. Further he should be asked to comment on the fact that in some circumstances the predicted loss is less than would be predicted by the free-space equation.

# Appendix A

**In a message dated 8/9/2011 12:33:27 P.M. Central Daylight Time, Ajay.Parikh@lightsquared.com writes:**

Bob,

Here are our comments on use of Hata model by RTCA:

The Hata model as adopted by RTCA is restricted to the frequency range of 150-1500 MHz and therefore may not be applicable to the LightSquared operating frequency range of 1525-1559 MHz. Under the European COST 231 program, Hata model was evaluated and found to produce consistently lower path losses in rural, urban, suburban and metro areas. They have developed a more accurate model (Extended Hata) for the frequency range of 1500 – 2000 MHz to correct the situation. It is very similar to the original Hata model, but differ slightly as shown below.

1. The main difference is the first two terms of path loss from the two version:

   For the regular Hata model (fc < 1500 MHz), the first terms is 69.55 + 26.16*log10(fc), which is equal to 152.9 dB if applied for fc = 1531 MHz.

   For the extended Hata model (fc >1500 MHz), the first terms is 46.3 + 33.9*log10(fc), which is equal to 154.3 dB if fc = 1531 MHz.

   Therefore, for fc = 1531 MHz, using regular Hata model would lead to 1.4 dB less loss.

2. RTCA Hata model uses the correction factor for ATC antenna height for a large city, which is logical. However, it uses an additional correction factor K, which should be used only to correct small city formula for suburban and open areas, which is given by 2[log10(fc/28)]^2 +5.4. At fc = 1531 MHz, this correction factor would provide 11.4 dB lower loss for each path. Since we are considering an aircraft near a large city, in our opinion, this suburban area loss correction should not be applied, which would result in aggregate path loss to be 8.9 dB higher at 535.2 meter aircraft height.

3. Because of above two assumptions made in the RTCA report, we believe the aggregated RFI path loss is substantially under-estimated in the report. Also it may explain why the RTCA Hata model has resulted in less path loss (2.6 dB less) than that from the free space model at Ha = 550m, which seems anomalous.

4. Following table compares the mean path losses computed by Hata model as used by RTCA, Extended Hata model , and Free Space propagation losses. As you can see at 2 Km and 10 Km distances the Hata model predicts path loss lower than Free space loss, which is inconsistent with the physics of propagation.

| Single path Distance in Km | Path Loss in dB | | |
|---|---|---|---|
| | Hata Model as used by RTCA | Extended Hata model (COST 231) | Free space |
| 2 | 96.1 | 112 | 102.2 |
| 10 | 115 | 130.9 | 116.2 |
| 20 | 123.2 | 139.1 | 122.2 |

5. It is found that the aggregate mean RFI path loss from probabilistic model is very sensitive to standard deviation (STD) of the individual path losses. Could you please explain the physics behind this phenomenon?

Please indicate at time when we could discuss this on a call.

## General Equation

6. PL = A + B log(d) + C

   where A,B, and C are factors that depend on frequency and antenna height.

### Hata Model

$A = 69.55 + 26.16 \log(fc) - 13.82 \log(hb) - a(hm)$
$B = 44.9 - 6.55 \log(hb)$

where fc is given in MHz and d in km.

The function a(hm) and the factor C depend on the environment as shown:

Small and medium-size cities:

$a(hm) = (1.1 \log(fc) - 0.7)hm - (1.56 \log(fc) - 0.8)$
$C = 0$

Metropolitan areas

$a(hm) = 3.2(\log(11.75hm)^2 - 4.97$ for $f \geq 400$ MHz (RTCA Model)
$C = 0$

Suburban environments

$C = -2[\log(fc/28)]2 - 5.4$ (RTCA Model)

Rural area

$C = -4.78[\log(fc)]2 + 18.33 \log(fc) - 40.98$

### COST 231 (Extended Hata) Model

$A = 46.3 + 33.9 \log(fc) - 13.82 \log(hb) - a(hm)$
$B = 44.9 - 6.55 \log(hb)$

where a(hm) is defined as in Hata model.

C is 0 in small and medium-sized cities, and 3 dB in metropolitan areas.

**Regards,**

**Ajay S Parikh**
**Programs Director,**
**Distinguished Member of Technical staff**

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# Appendix B

**In a message dated 8/12/2011 12:13:49 P.M. Central Daylight Time, ErlandRJ@aol.com writes:**

Ajay:
Ken Peterson and I have reviewed your comments below about the use of the Hata model as the basis for the long range propagation model in the RTCA study. For the reasons we discussed with you previously during the RTCA study period, we still believe the Hata model documented in DO-327 is the appropriate one to use rather than the COST231 model.

1) The basic reason is that the Hata-suburban formula is a closer upper bound to actual median path loss measurements in our representative airport environment than COST231. Barton (*The Mobile Radio Propagation Channel*, 2nd Ed., JW Wiley) notes that for loss measurements in typical US suburban areas the values vary between the "suburban" model and the "open" model predictions. COST231 predicts higher losses at the same reference distances

2) The basic Okumura loss measurements cover frequencies up to 1920 MHz. There is good agreement at frequencies between 1525-1575 MHz between the Hata model equation prediction and the sum of component values from the Okumura tables .

Note also that we only use the Hata-suburban model outside of about 20 km for the 535.2 m FAF WP case in DO-327 (see. Fig. B-3)

Attached is an excerpt from our ION Journal paper (in peer review) that we mentioned in the 8 Aug. telecon. It contains the description of the method to compute the CDF for received aggregate RFI power (Sec I, sub-part C.). Also included is an CDF example from the paper at 535.2 m aircraft height for a uniform distribution of RFI emitters having 1.8 m antenna height and 0 dBi hemispheric pattern (100 units per sq. km, ave.). .

Best regards,
Bob Erlandson

# DECLARATION OF JOHN DAVID PARSONS

I, John David Parsons, make the following declaration in connection with the FAA's Draft Status Report: Assessment of Compatibility of Planned LightSquared Ancillary Terrestrial Component Transmissions in the 1526-1536 MHz Band with Certified Aviation GPS Receivers dated December 23, 2011 ("FAA Report").

1. I am an Emeritus Professor and Honorary Senior Fellow at the University of Liverpool. I held the David Jardine Chair of Electronic Engineering from 1982 until 1998. During this period I was, at various times, Chairman and Head of the Department of Electrical Engineering and Electronics, Dean of the Faculty of Engineering and Pro-Vice Chancellor (Vice-President) of the University. I received a B.Sc. degree in Electrical Engineering (Magna cum Laude) from the University of Wales in 1959, an M.Sc. in Electronics from the University of London in 1967 and a D.Sc. in Electronic Engineering (Radiocommunications) from the University of London in 1985. I also hold the following certifications; FREng, (Fellow of the Royal Academy of Engineering, London) FIET, (Fellow of the Institution of Engineering and Technology - formerly the Institution of Electrical Engineers, London) and SMIEEE (Senior Member of the Institute of Electronics and Electrical Engineers, New York)

2. In addition to my teaching experience, I have conducted extensive research on various aspects of radio engineering, specializing in radio propagation and radio channel characterization particularly in connection with cellular systems, and have published approximately 150 technical papers in peer-reviewed Journals and at major conferences. I have also authored or co-authored 3 books on the topics of radio propagation and radio engineering. I have acted as a consultant to several companies and have given evidence as an expert witness in Courts of Law. A copy of my CV is attached to this Declaration.

3. I have been asked by LightSquared to review the proposed propagation models for determining the compatibility between LightSquared's terrestrial system and FAA GPS requirements. Most recently, I have been asked to review the FAA Report and

provide my opinion on the validity of the FAA's most recent propagation model described therein.

4. In my professional opinion, LightSquared's proposed approach to modeling propagation is scientifically valid and supported by available scientific literature. The company has drawn on well-established physical and engineering principles and models that have stood the test of time, to characterize the propagation scenario in which its proposed system will operate. At all times it has applied these principles with appropriate scientific rigour.

5. On the other hand, in my professional opinion, the approach to modeling propagation being proposed by the FAA and its consultants is often not supported by similar scientific evidence; it contains significant inconsistencies, and in many ways could be characterized as arbitrary.

I declare that the foregoing Declaration it true and correct.

Executed on January 9, 2012.

John David Parsons

John David Parsons

*CURRICULUM VITAE*

# PROFESSOR DAVID PARSONS

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## ACADEMIC AND PROFESSIONAL QUALIFICATIONS

1959 B.Sc., Electrical Engineering (Magna cum laude), University of Wales
1967 M.Sc. (Eng.) Electronics, Kings College, London
1985 D.Sc. (Eng.) University of London
Chartered Electrical Engineer
Fellow, Institution of Engineering and Technology (formerly the Institution of Electrical Engineers) (FIET)
Senior Member, Institute of Electrical and Electronic Engineers (SMIEEE)

## HONOURS

1988 Fellow, Royal Academy of Engineering (FREng.)

## CURRENT STATUS

Retired. Emeritus Professor at the University of Liverpool
Honorary Senior Fellow

## CAREER

1982 - 98 Professor of Electrical Engineering, University of Liverpool (Holder of the David Jardine Chair)

1983 - 86 and 1996 - 98
Head, Department of Electrical Engineering and Electronics

1986 - 1989 Dean, Faculty of Engineering
1990 - 1996 Pro Vice Chancellor

1969 - 82 University of Birmingham, Department of Electronic and Electrical Engineering;
1969 Lecturer, 1977 Senior Lecturer
1982 Reader in Radiocommunications

1966 - 68 City of Birmingham Polytechnic (now University of Central England), Principal Lecturer in Electronic Engineering.

| | |
|---|---|
| 1962 - 66 | The Polytechnic, Regent Street, London, (now University of Westminster). |
| 1959 - 62 | GEC Ltd., Applied Electronics Laboratories, Stanmore, Middlesex, Research and Development Engineer. |

## OTHER ACTIVITIES

| | |
|---|---|
| 1977 | United Nations Expert at the International Telecommunications Training Centre, New Delhi, India. |
| 1978 - 82 | Honorary Senior Principal Scientific Officer, Royal Signals and Radar Establishment (RSRE), Malvern. |
| 1982 | Visiting Professor in Electronic Engineering, University of Auckland, New Zealand. |
| 1987 | Visiting Research Engineer, NTT Radio Communication Network Laboratories, Yokosuka, Japan. |
| 1996 | Member, HEFCE National Panel for Electrical Engineering, Research Assessment Exercise |

Member of several IEE Committees and Boards.
Chairman IEE Professional Group E8 (Radiocommunication Systems), 1985-88.
IEE Council 1988-89.
Chairman, Mersey and North Wales Centre 1989-90.
Presented IEE Christmas Lecture 1992.
Advisor and Consultant to several industrial companies.

## TECHNICAL AND RESEARCH EXPERIENCE

My major technical interest is in the field of telecommunications and my involvement spans a period of over 45 years. Within that general field I have been principally interested in radio communication systems although I have always kept up to date with developments in telephone, television and cable systems. I am familiar with the principles and practical techniques used in analogue and digital radio systems in all frequency bands and have extensive knowledge and experience of first and second generation cellular radiotelephone systems.

As far as research is concerned I have wide interests but have specialised in tackling the problems of mobile, cellular and personal communication systems. A major theme of this research has been the characterisation of the radiocommunication channel; it has encompassed studies of propagation in urban areas and within buildings, man-made electrical noise, digital radio systems and channel simulation. I have also been actively involved in the development of radio system techniques, such as diversity reception, which can be used to mitigate the deleterious effects caused by the radio propagation channel. This research attracted considerable financial support. I always maintained a group of active research workers and during my career more than 30 successful Ph.D. theses were submitted by students who worked under my supervision.
I have given many invited lectures, seminars and overview addresses.

## CONSULTANCY

For many years I have been active as a radio and telecommunications consultant to industrial and government organisations. I have also written several reports in connection with cases of litigation and appeared as an expert witness in court cases. In 1988 I gave evidence before a Select Committee in the House of Lords.

Organisations which have sought my advice include:-

Air Call Ltd.
Cellnet
DTI (Radiocommunications Agency)
Ericsson Radio Systems AB
Government of the Isle of Man
Hutchison Microtel
London Fire and Civil Defence Authority
London Underground Ltd.
Mercury Personal Communications
Metropolitan Police
Racal Research Ltd.
Sinclair Communications
Mobile Systems International plc
Wragge and Co (Solicitors) Birmingham
Louis Berkson and Globe (Solicitors) Liverpool

## PUBLICATIONS

Books

"The Mobile Radio Propagation Channel", John Wiley, 1992.(second edition , 2000)

"Mobile Communication Systems", (with J. G. Gardiner), Blackie and Sons, 1988.

"Electronic and Switching Circuits", (with S. M. Bozic and R. Cheng), Edward Arnold, 1975.

Contributions to several other books.

Over 100 papers published in international professional engineering journals.

4 "best paper"(premium) awards from the IEE for published papers in 1975, 1982, 1983 and 1992.

# DECLARATION OF JOHN HOWARD GLOVER

I, John Howard Glover, make the following declaration in connection with the Letter from Lawrence E. Strickling, Assistant Secretary for Communications and Information, U.S. Dep't of Commerce, to Julius Genachowski, Chairman, FCC (dated Feb. 14, 2012) ("NTIA Letter") and the U. S. Department Of Transportation Federal Aviation Administration Status Report: Assessment Of Compatibility Of Planned LightSquared Ancillary Terrestrial Component Transmissions In The 1526-1536 MHz and With Certified Aviation GPS Receivers (Jan 25, 2012) ("FAA Report").

1. I have worked for more than 35 years on the development, flight testing and certification of terrain awareness and alerting systems ("TAWS"). My experience includes early Ground Proximity Warning systems for civil and military aircraft and also modern Terrain and Obstacle Awareness and Warning systems and displays. I served as secretary of the EUROCAE working group which developed TAWS design standards for US and European certification. I hold more than a dozen patents in the field of airborne alerting systems. I was an FAA Systems and Equipment Designated Engineering Representative for more than 20 years. A copy of my CV is attached to this Declaration..

3. I have been asked by LightSquared to review the FAA's proposed requirements to use to evaluate the impact of LightSquared's system on TAWS. More recently, I have been asked to review the TAWS evaluation criteria in the FAA Report attached to the NTIA Letter.

4. In my professional opinion, the FAA's proposed TAWS evaluation criteria are overly restrictive and do not take into account operational considerations, the many

redundancies in commercial TAWS systems to ensure functionality, or that most commercial TAWS systems are more robust than the Minimum Operational Performance Standards ("MOPS") contained in the FAA Technical Standard Orders ("TSOs") related to TAWS.

5. In my professional opinion, the FAA Report overstates the likelihood that temporary loss of a GPS signal would significantly degrade operational safety of flight. Most significantly, in the process of descending to an altitude low enough for the system to be exposed to interference-induced loss of GPS data, the airplane must pass through an environment where a TAWS alert will be given before that airplane enters the very low altitude zone. In this case it can be assumed that the flight crew will have taken action to avoid the terrain or obstacle threat before the loss of signal has occurred.

6. TAWS systems are divided into three classes – A, B, and C – all of which may use GPS position data to locate the aircraft with respect to the terrain database and also with respect to a runway. Class A Systems are required to be installed on all aircraft operating under Part 121 and commercial aircraft operating under Part 135 with more than 9 seats. Class B Systems are required for all aircraft operating under Part 135 with between 6 and 9 seats or Part 91 aircraft with 6 or more seats. Class C applies to small general aviation aircraft not required to have TAWS systems installed.

7. Class A TAWS are not required to use GPS as a position data source. Some systems obtain position data from a Navigation Computer that blends, Inertial Reference

System data (and for some systems also Radio Navigation data) in order to calculate aircraft position. Other systems do use GPS data in addition to the previously mentioned sources. For any of these systems, the loss of GPS signal does not degrade the position data until Inertial Reference System drift errors become significant – typically only after several minutes. Consequently, Class A TAWS systems operating in an airport terminal airspace environment are relatively immune to loss of GPS data.

8. All FAA certified TSO-C151b Class A and B systems with internal GPS receivers must have the capability of monitoring the validity and position error of the GPS system, and the TAWS must provide an indication to the pilot if the GPS error is excessive. Even if a GPS signal were lost for these systems, the flight crew would be aware of the loss and use back-up systems to ensure continued operational safety.

9. Class A TAWS systems have several alerting functions that use Radio Altimeter signals for determining the height of the airplane above the terrain. These functions are independent of GPS position data. For example, the DO 161A Mode 4 “Too Low” alert mode provides an alert if the airplane descends below 500 feet with the landing gear up, and provides an alert if the airplane descends below 200 feet if the landing gear is down but landing flaps are not set. An advisory call is also required when the airplane descends below 500 feet, irrespective of configuration. This alert would occur even if the TAWS GPS receiver component signal were lost.

10. If a loss of GPS signal occurs while a TAWS alert in progress, it would be improbable that the pilot would assume that the terrain threat has ceased. The correct pilot response to a TAWS alert is to ensure adequate terrain clearance, pilots are trained extensively in TAWS avoidance procedures. The following is an excerpt from Pilot Guide/Flight Manual Supplement for systems provided by a TAWS manufacturer:

> Recommended response to EGPWS alerts are as follows:
> **Caution:**
> 1. Stop any descent and climb as necessary to eliminate the alert. Analyze all available instruments and information to determine best course of action.
> 2. Advise ATC of situation as necessary.
>
> **Warning:**
> 1. Aggressively position throttles for maximum rated thrust. Apply maximum available power as determined by emergency need. The pilot not flying (if applicable) should set power and ensure that TO/GA power and modes are set.
> 2. If engaged, disengage the autopilot and smoothly but aggressively increase pitch toward "stick shaker" or Pitch Limit Indicators (PLI) to obtain maximum climb performance.
> 3. Continue climbing until the warning is eliminated and safe flight is assured.
> 4. Advise ATC of situation.
>
> **NOTE:** Climbing is the only recommended response unless operating in visual conditions and/or pilot determines, based on all available information, that turning in addition to the climbing is the safest course of action. Follow established operating procedures.

11. TSO C-151b requires that Class A and B systems provide Forward Looking Terrain Avoidance (FLTA) and Premature Descent Alert (PDA) functions that provide alerts on a slope rather than a stepped basis as in the TSO to accommodate typical ascent and descent procedures near airports. A typical TAWS system (*e. g.* the Honeywell EGPWS) implements PDA function with a "Terrain Clearance Floor" function (see drawing below). The "floor" slopes upwards from the threshold of the nearest runway, reaching a height of 400 feet at 4 nautical miles from the threshold. It then remains at 400

feet until 12 nautical miles, when it again slopes up to 700 feet at 15 nautical miles. If an airplane descends below this floor an alert is provided, irrespective of landing gear position or flap setting. The floor begins at a distance from the runway threshold that varies with the quality of position data, but is typically ¼ nautical mile. Current systems provide further protection by holding the height of the floor at a minimum of 245 feet unless the airplane track is aligned with the runway within +/- 45 degrees, thus ensuring that an airplane that is not within the approach corridor will receive a terrain alert at a minimum height of 245 feet.

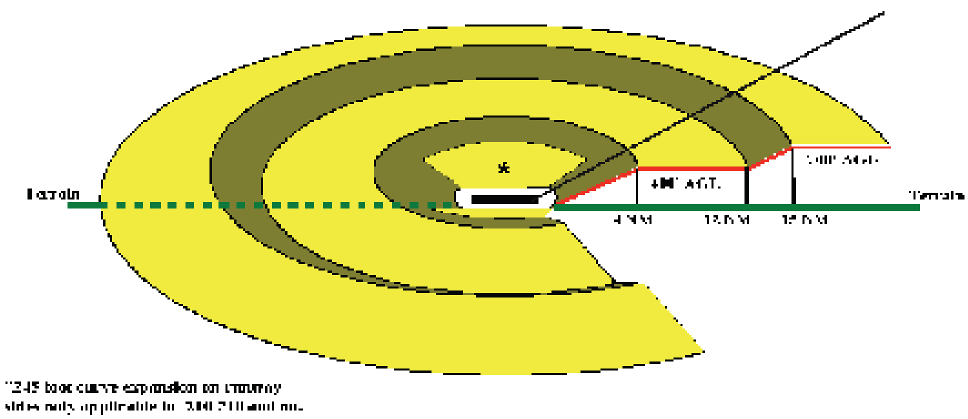


Figure 1.1- Terrain Clearance Floor

Even when the airplane is above the clearance floor, if it is descending at an angle such that its flight path is predicted to intersect the ground before the runway, then the required Forward Looking Terrain Avoidance function will provide an alert. This PDA function ensures that if an airplane is not aligned with the approach corridor to a runway, then a terrain alert will be given if the airplane descends below 245 feet.

If the airplane is within the approach corridor, then a descent below 200 feet will result in an alert unless the airplane is closer than 2¼ nautical miles to the runway threshold, and a descent below 100 feet will result in an alert unless the airplane is closer than 1¼ nautical miles to the runway threshold.

Consequently, if GPS signals are available when the airplane is above 200 feet, and are subsequently lost when the airplane continues to descend, there is a very small volume of unprotected airspace close to the runway. If an airplane is established on an approach path which is sufficiently stable to not generate a terrain alert above 200 feet, then it is considered to be very improbable that anything less than an extreme deviation from the stabilized path below this height would result in a terrain collision. Such an extreme maneuver is likely to result in an accident even if the TAWS function were fully operational.

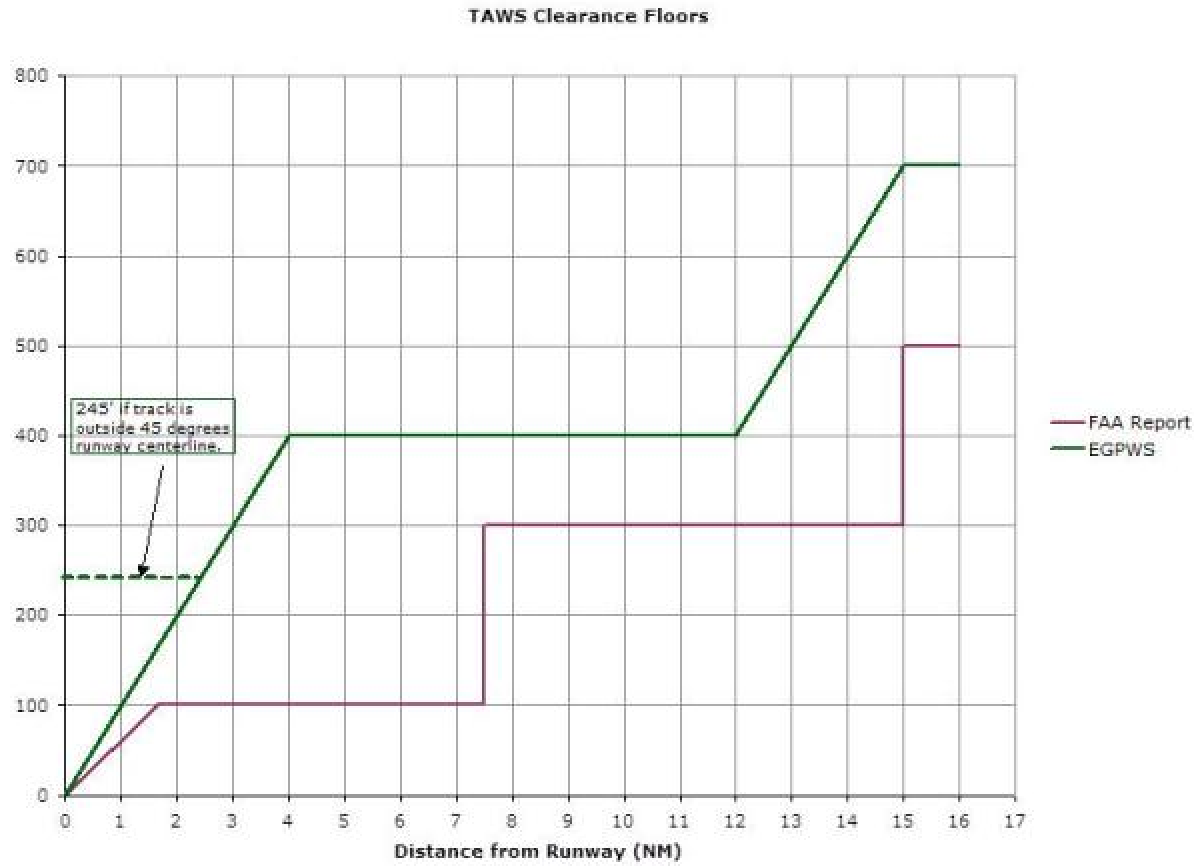


Figure 1.2 - Terrain Clearance Floors: Typical Production Equipment vs. FAA Minimum Requirements.

12. While not mandated, TAWS systems increasingly incorporate obstacle information in their databases. When an obstacle database is available, TAWS alerts are triggered at higher altitudes. Obstacle databases are continually being improved, but typically include obstacles such as buildings, cell/antenna towers, and other manmade structures that exceed 100 feet above ground level close to an airport, and also such structures that exceed 200 feet above ground level further away from an airport. From an operational standpoint, TAWS databases with obstacles allow the TAWS systems to sound alerts above the obstacles, providing more realistic TAWS protection. Since most LightSquared antennas will be mounted on structures that would be included in these obstacle databases, and because such obstacles would cause the TAWS to provide an

alert before the airplane descends to an altitude where interference with the GPS signal is likely, a more realistic TAWS scenario would include these obstacles in the analysis.

13. The FAA's application the requirements of TSO-C151b (Terrain Awareness and Warning System (TAWS)) (the "TAWS TSO") to evaluate the whether LightSquared's proposed system will interfere with TAWS is overly conservative. The TAWS TSO itself provides flexibility not included in the FAA's Report. For example, Appendix 1 Table 3.1.1, which appears to form the basis for the FAA's evaluation criteria in Section 1.4. of the FAA Report, does not mandate a 100' clearance in all Departure and Approach Phases. Specifically:

- The RTC values are for the *projected* terrain clearance (i.e. the clearance which the system predicts the airplane will have if it continues along its current flight path). If the airplane is descending, the terrain clearance directly beneath the airplane will generally be greater, and so the vertical distance between the airplane and any tower beneath the airplane will also be greater than the RTC value.
- Table 3.1.1 Note 2 allows "…a linear reduction of the RTC as the aircraft comes closer to the nearest runway…" instead of the step reduction implied by the Table. Indeed, as noted above, most TAWS equipment today uses such a linear approach.
- Table 3.1.1 Note 3 allows the RTC to be reduced within 1 NM of the runway, and does not mandate the 100' clearance within this radius.

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14. In conclusion, the FAA report fails to demonstrate that a temporary loss of GPS at low altitudes would result in a significant degradation of safety related to TAWS. Actual TAWS systems are far more robust and contain numerous safeguards to ensure operational safety.

* * * *

I declare under penalty of perjury under the laws of the United States of America that the foregoing Declaration is true and correct.

Executed on March 15, 2012

John Howard Glover

John Howard Glover

## John Howard Glover

Total years of experience in aviation industry: *49*
Areas of technical expertise:

- ***Aircraft Operations Analysis***
- ***Alerting Systems Design***
- ***Flight Deck Design***
- ***Systems Certification***

Education:

- ***B.Sc. (Honors): Aeronautical Engineering, Imperial College, London University, UK***
- ***Advanced degree: Associate of City and Guilds Institute (London University): Aeronautical Engineering.***

Experience:

- ***British Aircraft Corp., Bristol, UK (2 years): Research Engineer. Development of missile guidance systems.***
- ***British Royal Aircraft Establishment (2 years), Bedford, UK: Scientific Officer. Development and flight testing of tactical landing system for V/STOL aircraft.***
- ***The Boeing Co., Seattle, WA (9 years): Staff Engineer. Development of flight deck alerting systems, B747 airplane. Development and flight testing of fly-by-wire control system for proposed B707 patrol airplane. Development of advanced propulsion control systems.***
- ***Sundstrand Data Control/Allied Signal/Honeywell, Redmond, WA (36 years): Engineering Fellow. Development, marketing, flight testing and certification of flight safety products.***
- ***Member/officer on several aviation industry technical committees in the USA and Europe:***
    - ***Member of SAE S-7 committee (Transport Airplane Handling Qualities and Flight Deck Design Standards),***
    - ***Secretary of EUROCAE Working Group 44 (Terrain Awareness Warning System design standards),***
    - ***Member of RTCA committee SC-186 (Aircraft Surface Alerting standards).***

Professional Memberships: ***Fellow, Royal Aeronautical Society, UK***

Other Qualifications:

- ***FAA licensed multi-engine and instrument rated commercial pilot (airplane, helicopter and glider).***
- ***Author of several patents in the flight safety and control domains.***
- ***FAA Systems DER for more than 20 years***

**EXHIBIT C**

**GPS RECEIVERS CAN FILTER LIGHTSQUARED'S SIGNALS WITHOUT DEGRADING THEIR PERFORMANCE**

The GPS interests have, on several occasions, argued that it is impossible to sufficiently attenuate adjacent band LightSquared signals without sacrificing the present performance of GPS receivers.[1] This claimed is refuted below.

The claim of the GPS interests is based on the following arguments.

1. Bandpass filters necessarily involve insertion loss which can result in a degradation of the receiver's noise figure.

2. Bandpass filters necessarily involve group delay variation with frequency. This degrades position accuracy.

3. Restricting the bandwidth of the received GPS signal can degrade the position accuracy.

4. The filters required will be too large for the current form factors of GPS receivers and/or will cost too much.

## I. PRESELECTOR FILTER INSERTION LOSS AND POTENTIAL DEGRADATION IN RECEIVER NOISE FIGURE

An individual filter offering in excess of 45 dB rejection of the lower 10 MHz ATC channel (1526 – 1536 MHz) will typically have an insertion loss of approximately 2 dB at the GPS L1 frequency. An example of such a filter is provided in Attachment C-1. The above 2 dB insertion loss does not have to result in a 2 dB increase in the receiver's noise figure as a low-gain high-linearity LNA can precede the filter to reduce the impact on receiver noise figure. An example of how the insertion loss of the filter can be masked from affecting the noise figure is provided below using commercially available RF components.

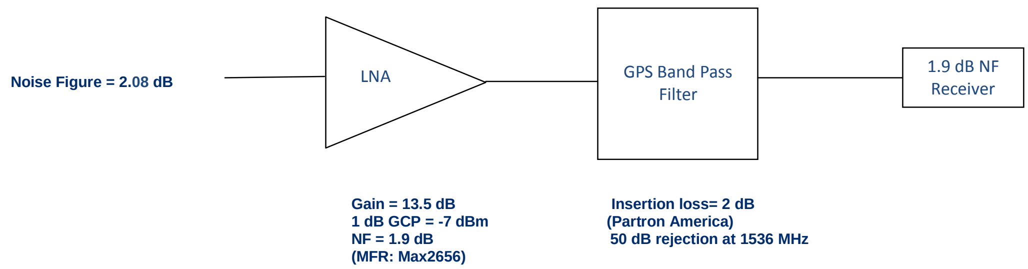
This example assumes the following:

- Receiver with a 1.9 dB Noise Figure without any LNA/Filter modifications;
- The cascaded Noise Figure of the receive chain is 2.08 dB;
- Linear noise amplifier (LNA) with 1 dB Input Gain Compression point of -7 dBm;
- LightSquared base station signal level = - 20 dBm.

In these conditions, the small signal gain suppression of the LNA will be negligible (~0.01 dB). Even assuming a higher than typical base station signal level of -20 dBm, the small signal suppression will be ~ 0.1 dB.

[1] *See e.g.* Garmin International, Inc., Comments, FCC File No. SAT-MOD-201011118-00239 and IB Docket 11-109 (August 1, 2011).

**Figure C.I.1**




## II. GROUP DELAY VARIATION IN THE RNSS PASSBAND

Much has been made of this subject by the GPS interests at various times.[2] The arguments have included the following:

- Group delay variation in the passband causes correlation loss (the cross-correlation function between the received GPS signal and its local replica in the GPS receiver will have a smaller peak).

- Interchannel biases could be introduced in the processing of the GPS signals from different satellites if the frequency spectra of the GPS signals were not identical (owing to the use of different spreading codes). This problem is more pronounced for FDMA constellations such as GLONASS than CDMA constellations such as GPS (and next generation GLONASS).

### A. Correlation Loss

This is a purely hypothetical concern. Extensive simulations performed by LightSquared have shown that the loss of correlation is less than 0.27 dB for the P(Y) code and 0.05 dB for the C/A code. The bandpass filter simulated was a 12th order Chebyshev type-I filter with 90 ns of group delay variation between 1559 and 1605 MHz and 55 dB rejection at 1535 MHz.

#### 1. Interchannel Bias

The potential for interchannel bias in CDMA based signals, such as GPS, is a *theoretical* possibility.[3] However, actual measurements with both GPS simulators and live-sky GPS signals

[2] *See e.g.* Letter from F. Michael Swiek, Executive Director, U.S. GPS Industry Council to Marlene H. Dortch, Secretary, FCC, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (January 12, 2012) (citing Hemisphere's concerns about failure to explore the impact of group delays). *See also* Letter from Catherine Wang, Bingham McCutchen LLP to Marlene H. Dortch, Secretary, FCC, FCC File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (October 27, 2011) (noting that Deere & Co., Garmin Intentional, Inc., and Trimble Navigation Ltd. disclosed concerns about group delay in ex parte discussion with the FCC).

showed no systematic performance degradation when an existing high precision receiver was compared with a modified version, which had its frequency selectivity substantially enhanced. The results are provided in Attachment C-2.

### 2. Filter Size and Cost

The filter size and cost issue is addressed below according to GPS receiver class.

#### a) Cellular

For processing exclusively GPS L1 signals, cell phones do not need new filtering technologies. The TWG and NTIA tests showed that LightSquared's deployment plans with the lower-10 MHz channel posed no threat to present day cell phones. The potential need for better filtering applies only to circumstances not relevant here: cell phone GPS receivers which wish to process both GPS and GLONASS, and possibly Galileo in the future. These constellations require the passband of the filter to pass the entire 1559-1605 MHz RNSS band whereas legacy, GPS-only receivers typically have a passband smaller than the RNSS band.

Even if those other circumstances were taken into account, Avago Technologies has considered this new requirement and demonstrated that film bulk acoustic resonator (FBAR) technology exists today to manufacture filters, with the same form factor as legacy SAW filters, offering at least 40 dB rejection in the stopbands 1525-1555 MHz and 1626.5-1660.5 MHz, with minimal insertion loss and performance that is stable across a wide range of temperatures.[4] Qualcomm has indicated that it should not add more than about 5 cents to the current manufacturing cost of such a filter to provide this type of increased performance.[5]

#### b) Personal/General Navigation

The small number of legacy personal/general navigation devices which showed low overload thresholds (below -30 dBm) in both TWG and NPEF tests were essentially poor designs that offered no additional functionality or performance to offset of their more fragile performance. For these receivers, there is no uncertainty about how to improve their performance – simply replicating the design of another receiver that is more robust suffices.

For the future (if more satellite constellations are needed to be accommodated) this receiver class could use the same technology as cell phones; hence the same discussion applies.

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[3] Johnson, G. and Zaugg, T., "Measuring Interchannel Bias in GPS Receivers," Proceedings of the 57th Annual Meeting of The Institute of Navigation, Albuquerque, NM, June 2001, pp. 477-480 ("Johnson, *et al.* [1]").

[4] Working Group, Final Report, App. C.2, at 9 (June 30, 2011) ("TWG Final Report [5]") ("Present Avago FBAR manufacturing technology can support a filter with <1.5 dB insertion loss across narrow GPS + GLONASS (1574-1606 MHZ) that provides 40 dB of rejection in the [adjacent] bands. This performance can be maintained across manufacturing variation and a temperature range of -30 to +85 C.").

[5] TWG Final Report [5], at App. C.5, at 7-8 ("The cost impact could be on the order of 5 cents, depending on volume.").

### c) High Precision Positioning

After LightSquared published its results from the ALU tests of improved high precision receivers, the USGIC in its FCC *ex parte*[6] suggested that the improved antennas tested could only be used as external antennas (thereby limiting their applicability), allegedly because they used large filters. This is not necessarily true as demonstrated by Javad GNSS, which achieved improved frequency selectivity through a cascade of LNAs and SAW filters. While the Javad antenna tested in the ALU tests was indeed an external antenna, to allow it to be tested with other manufacturers' receivers, Javad has also created a compact high precision receiver with an internal antenna that is robust against LightSquared's lower 10 channel. Figure C.II.1 shows and picture of the compact Javad GNSS antenna which can withstand LightSquared's lower 10 MHz signal at a level above -10 dBm. The dimensions are approximately 178x109x178 mm.

**Figure C.II.1 Example of Compact High Precision Receiver with internal antenna. This receiver can withstand LightSquared's lower-10 MHz signal at a level above -10 dBm.**


Javad's design approach of concurrently increasing frequency selectivity and preserving linearity through a cascade of inexpensive, commercially available LNAs and SAW filters demonstrated that reducing susceptibility to overload from adjacent band signals is not necessarily associated with a cost increase for device components. It simply requires a redesign of the RF front end, which may actually reduce costs by introducing the opportunity to use newer less costly components.

### d) High Precision Timing

There are a relatively small number of high precision timing receivers which use carrier phase based techniques to derive very accurate timing references (with accuracy of less than 1 ns). These receivers are susceptible to an additional, potential error source not faced by high precision positioning receivers – errors in the receiver's delay calibration.[7] The receiver delay

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[6] USGIC Ex Parte [3].

[7] The net receiver delay cancels out in position estimation.

includes the propagation delay of the GPS signal from the antenna phase center to the point in the receive chain where the time observation is made. It has been suggested by GPS interests that, if the antenna is changed to make it more robust to LightSquared's signals, the delay calibration will be disturbed and therefore the receiver's timing accuracy will be degraded. Furthermore, filtering to increase frequency selectivity may make the delay calibration more vulnerable to temperature changes. These criticisms are addressed below.

The delay calibration is an established procedure that is required to be performed both at the time of initial installation and subsequently if any element of the receiver chain is changed. Moreover, thermal stabilization of the receiver is often performed even in present applications.[8] Schildknecht, *et al.* [6] point out that it is difficult to achieve typical high precision timing objectives without thermal stabilization. Hence, none of the criticisms against the feasibility of making High Precision Timing receivers more robust (through improved frequency selectivity) appear to be valid.

[8] Schildknecht, T. and Dudle, G., "Time and Frequency Transfer High Precision GPS Phase Measurements', GPS World, February 2000, pp, 48 – 52 ("Schildknecht, *et al.* [6]").

## References


[1] Johnson, G. and Zaugg, T., "Measuring Interchannel Bias in GPS Receivers," Proceedings of the 57th Annual Meeting of The Institute of Navigation, Albuquerque, NM, June 2001, pp. 477-480.

[2] Wanninger, L., “Carrier-Phase Inter-Frequency Biases of GLONASS receivers,” J. Geod., July 2011, DOI 10.1007/s00190-011-0502-y.

[3] United States GPS Industry Council, *Ex Parte Response Letter*, File No. SAT-MOD-20101118-00239 and IB Docket No. 11-109 (January 12, 2012).

[4] Kaplan, E. D. and Hegarty, C., Understanding GPS Principles and Applications (2 Ed.), Artech House, 2006.

[5] Working Group, Final Report, App. C.2, at 9 (June 30, 2011).

[6] Schildknecht, T. and Dudle, G., “Time and Frequency Transfer High Precision GPS Phase Measurements’, GPS World, February 2000, pp, 48 – 52.

## Attachment C-1

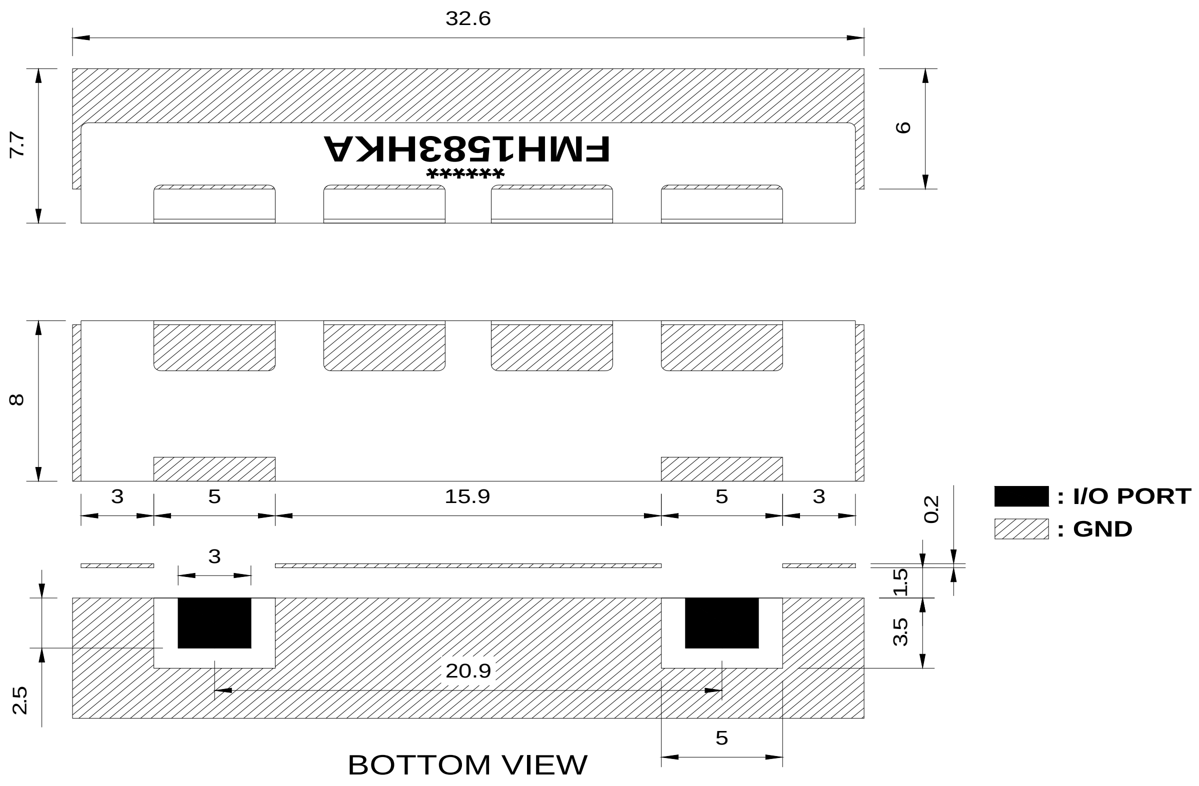
## Example of GPS Preselector Filter Specifications

| | | |
|---|---|---|
| VERSION | : | 2.0 |
| WRITTEN BY | : | DUCK-HAN KIM. |
| CHECKED BY | : | JI-MAN RYU. |
| ISSUED DATE | : | 2011.10.07 |
| PART NUMBER | : | EMH1583HKA |

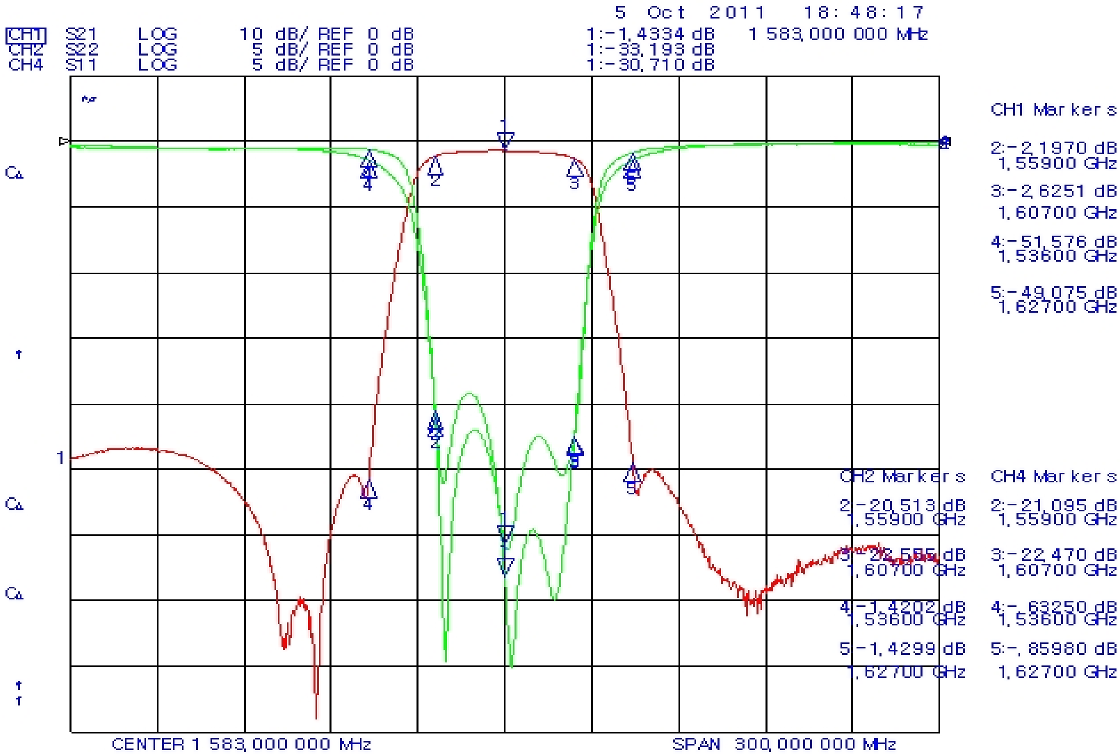
### 1. ELECTRICAL SPECIFICATION

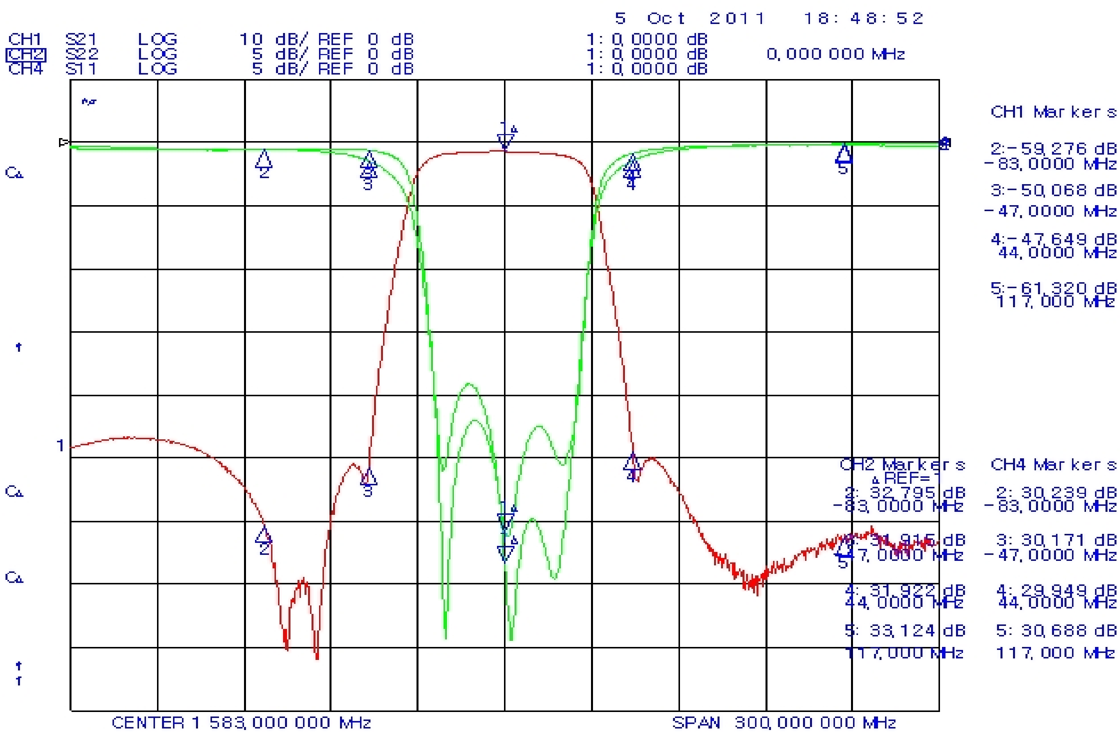
| ITEMS | | SPEC. | | |
|---|---|---|---|---|
| | | Typ. | @ 25℃ | @ -40 ~ +85℃ |
| Center frequency | | 1583 MHz | | |
| Bandwidth | | 1559 ~ 1607 MHz | | |
| Insertion Loss (@1583 MHz) | | 1.65 | 1.8 dB Max. | 2.0 dB Max. |
| Insertion Loss (@1559 ~ 1607 MHz) | | 2.8 | 3.0 dB Max. | 3.2 dB Max. |
| Ripple 1 (@1559 ~ 1607 MHz ) | | 1.2 | 1.5 dB Max. | 1.6 dB Max. |
| Ripple 2 (@1565.2 ~ 1585.6 MHz ) | | 0.3 | 0.4 dB Max. | 0.5 dB Max. |
| G.D.V 1 (@1559 ~ 1607 MHz) | | 20 | 25 nS Max. | 25 nS Max. |
| G.D.V 2 (@1565.2 ~ 1585.6 MHz) | | 8 | 10 nS Max. | 10 nS Max. |
| Return Loss | | 17 | 14.0 dB Min. | 14.0 dB Min. |
| Attenuation | @ 1500 ~ 1536 MHz | 50.0 | 45 dBc Min. | 45 dBc Min. |
| | @ 1627 ~ 1700 MHz | 47.0 | 45 dBc Min. | 42 dBc Min. |
| Input Power | | 3 W Max. | | |
| Operating Temperature | | -40℃~ +85℃ | | |
| In/Out Impedance | | 50 ohm | | |

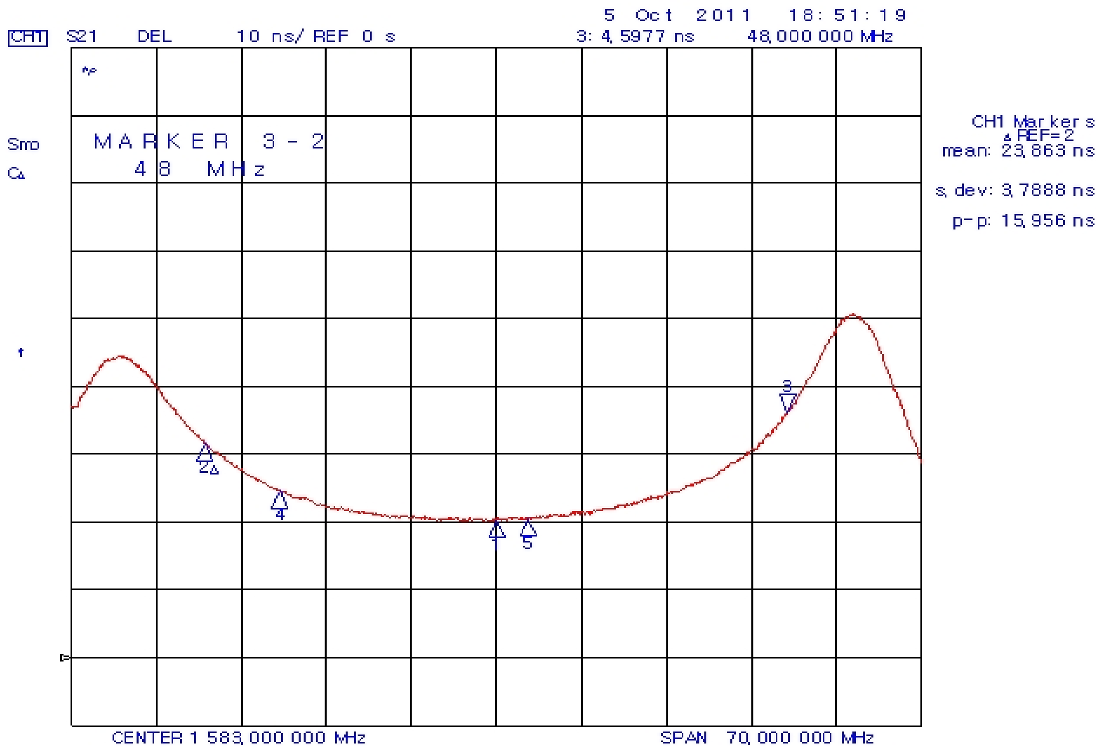
## 2. MECHANICAL SPECIFICATION

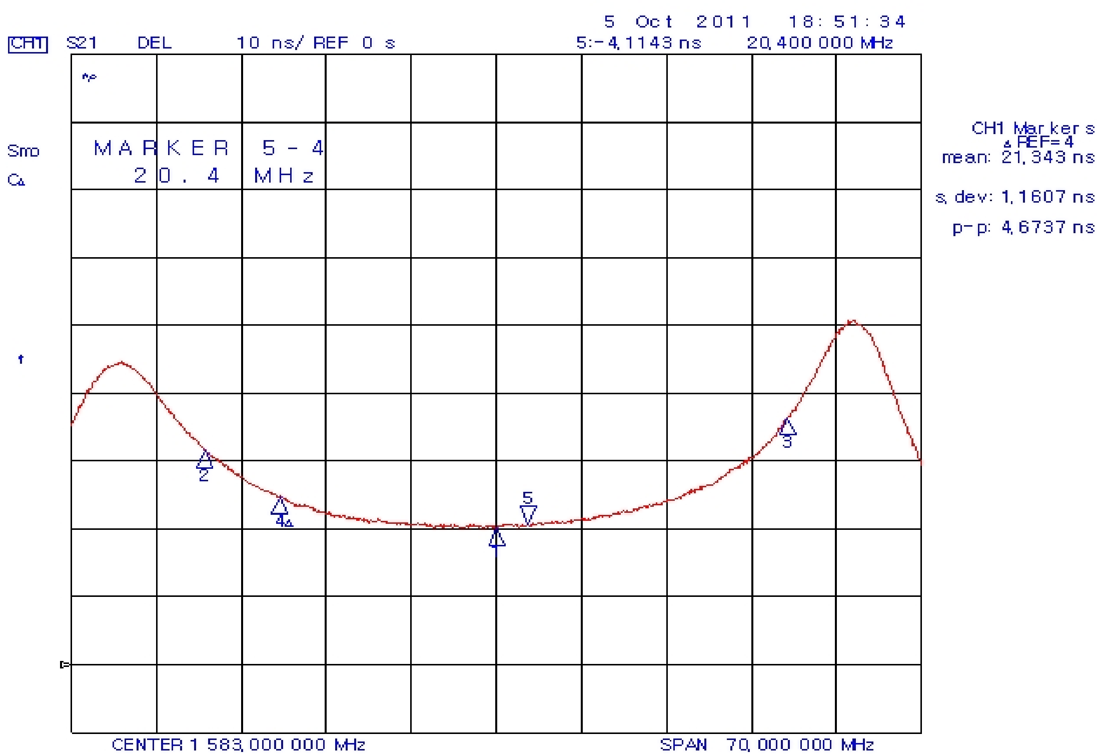


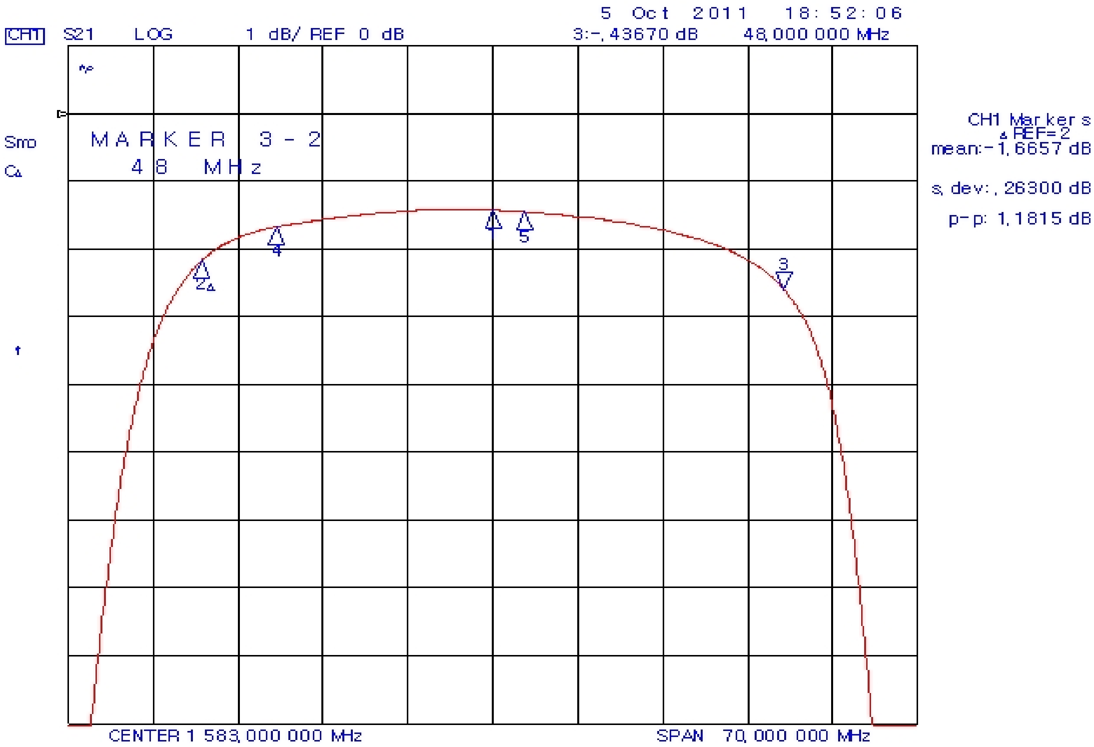
## 3. PLOT DATA (@ 25º)

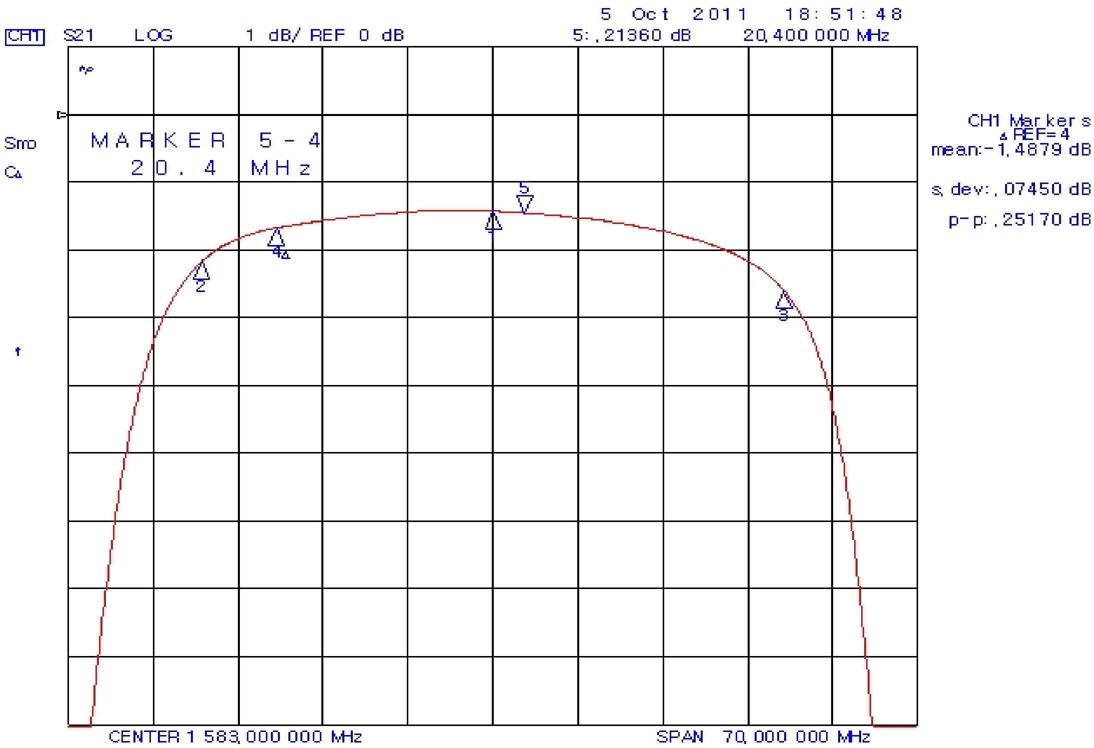


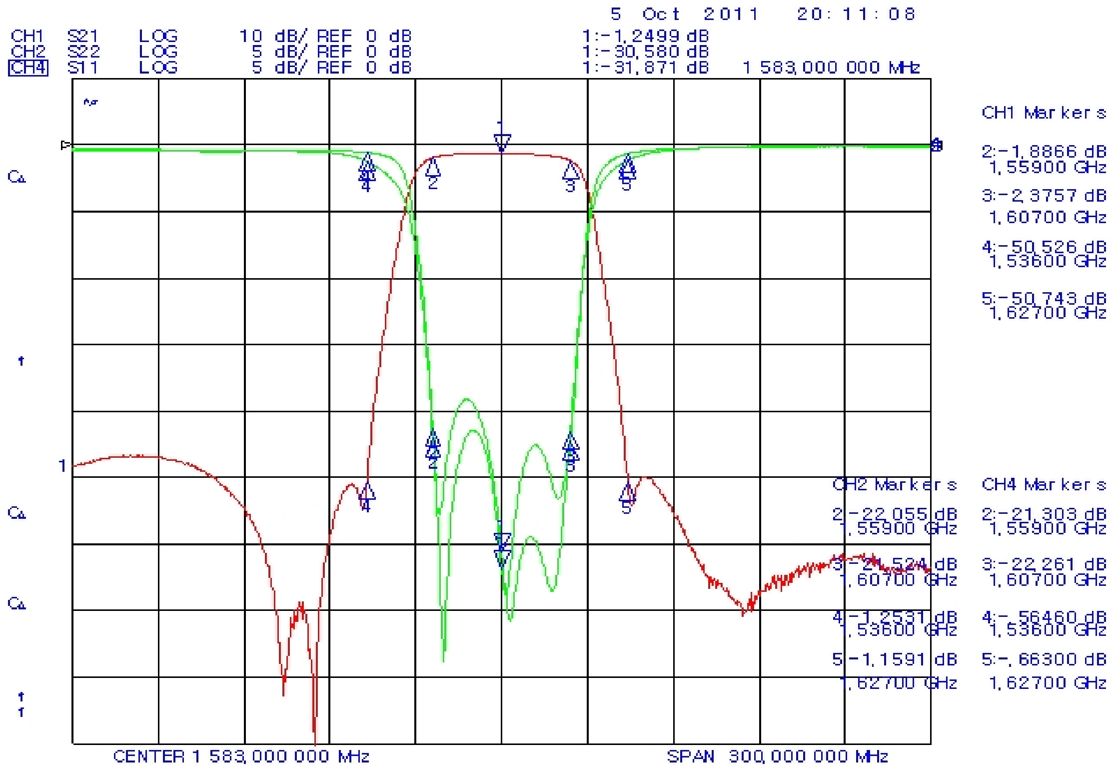

5 Oct 2011 18: 51: 19
CH1 S21 DEL 10 ns/ REF 0 s
3: 4, 5977 ns 48, 000 000 MHz
MARKER 3 - 2
48 MHz
Smo
Ca
CH1 Markers
Δ REF= 2
mean: 23, 863 ns
s. dev: 3, 7888 ns
p-p: 15, 956 ns
CENTER 1 583, 000 000 MHz
SPAN 70, 000 000 MHz

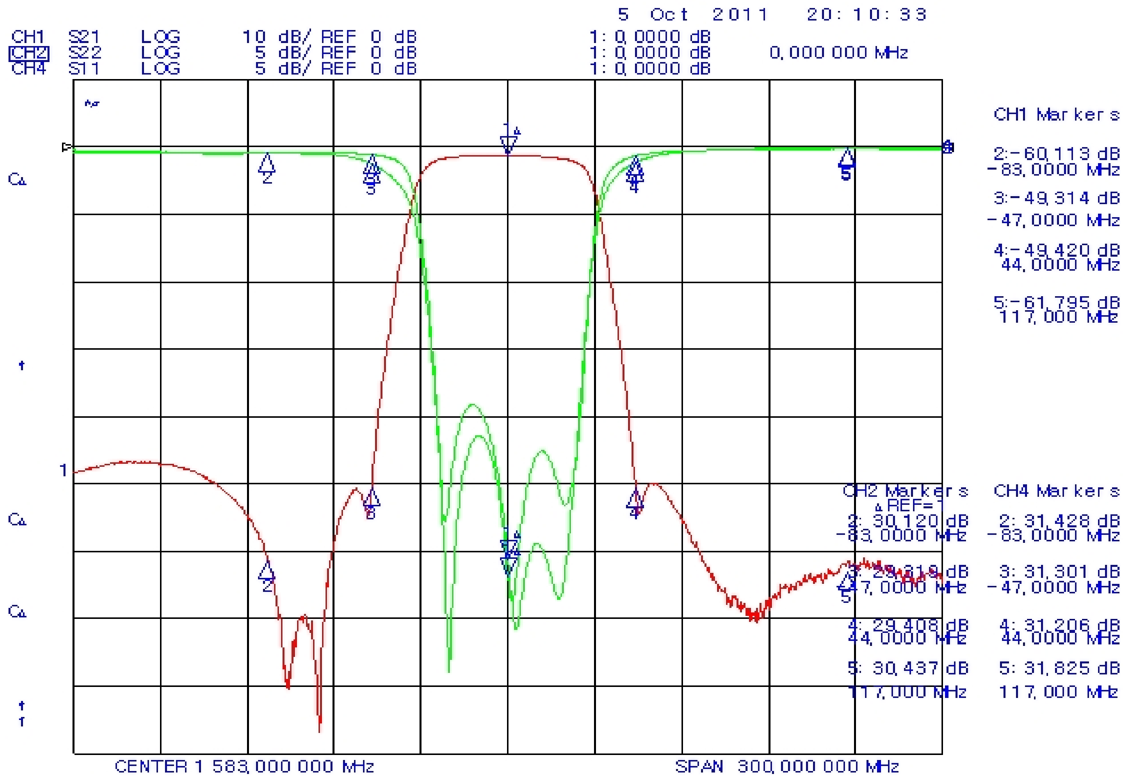

5 Oct 2011 18: 51: 34
CH1 S21 DEL 10 ns/ REF 0 s
5:-4, 1143 ns 20, 400 000 MHz
MARKER 5 - 4
20. 4 MHz
Smo
Ca
CH1 Markers
Δ REF= 4
mean: 21, 343 ns
s. dev: 1, 1607 ns
p-p: 4, 6737 ns
CENTER 1 583, 000 000 MHz
SPAN 70, 000 000 MHz

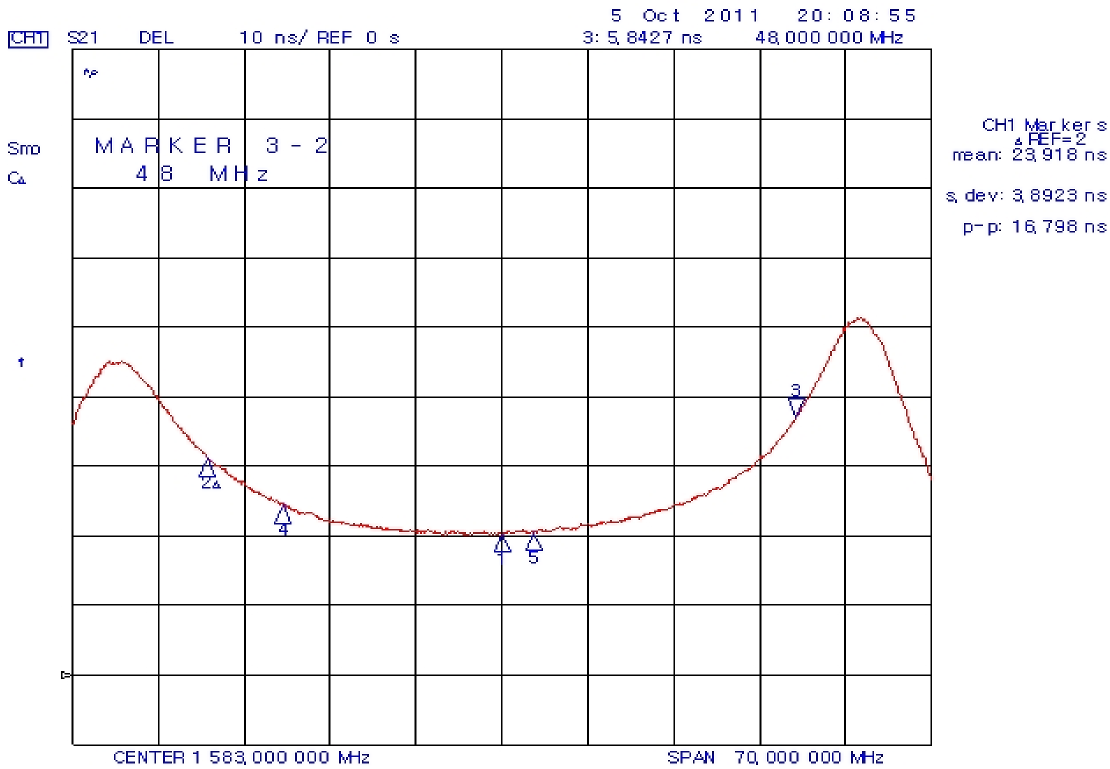

5 Oct 2011 18:52:06
CH1 S21 LOG 1 dB/ REF 0 dB
3:-,43670 dB 48,000 000 MHz
Smo
Ca
MARKER 3 - 2
48 MHz
CH1 Markers
Δ REF=2
mean:-1,6657 dB
s. dev: ,26300 dB
p-p: 1,1815 dB
CENTER 1 583,000 000 MHz
SPAN 70,000 000 MHz

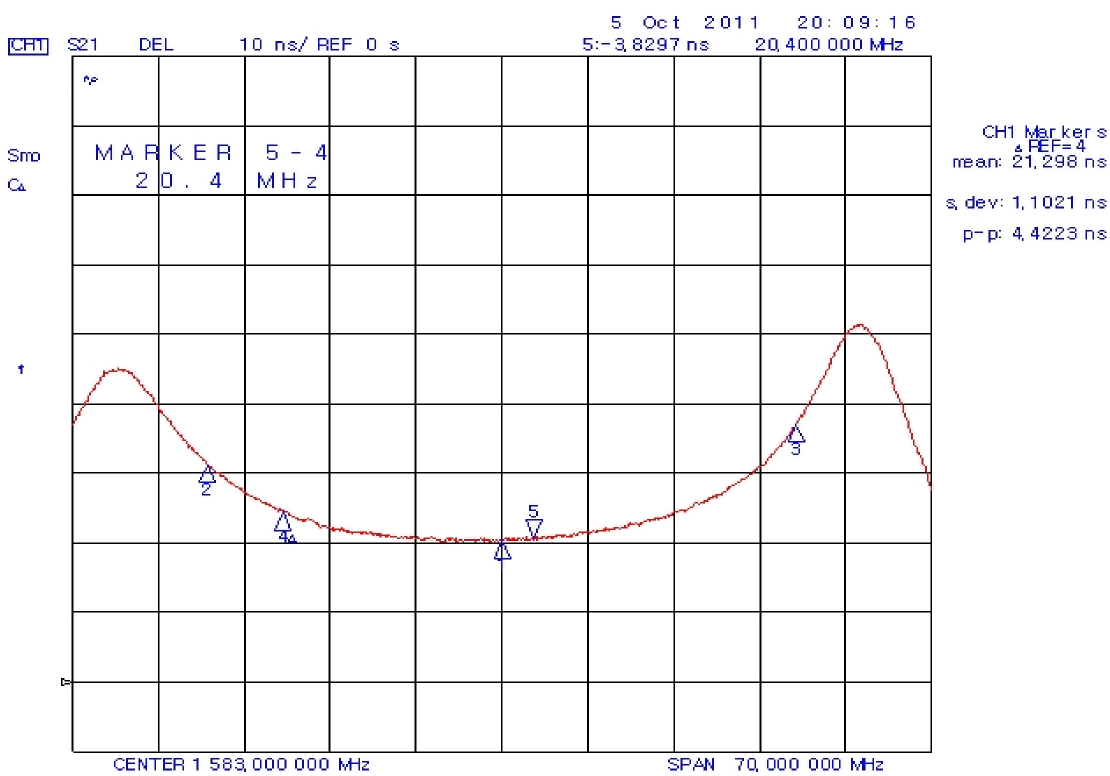

5 Oct 2011 18:51:48
CH1 S21 LOG 1 dB/ REF 0 dB
5: ,21360 dB 20,400 000 MHz
Smo
Ca
MARKER 5 - 4
20.4 MHz
CH1 Markers
Δ REF=4
mean:-1,4879 dB
s. dev: ,07450 dB
p-p: ,25170 dB
CENTER 1 583,000 000 MHz
SPAN 70,000 000 MHz

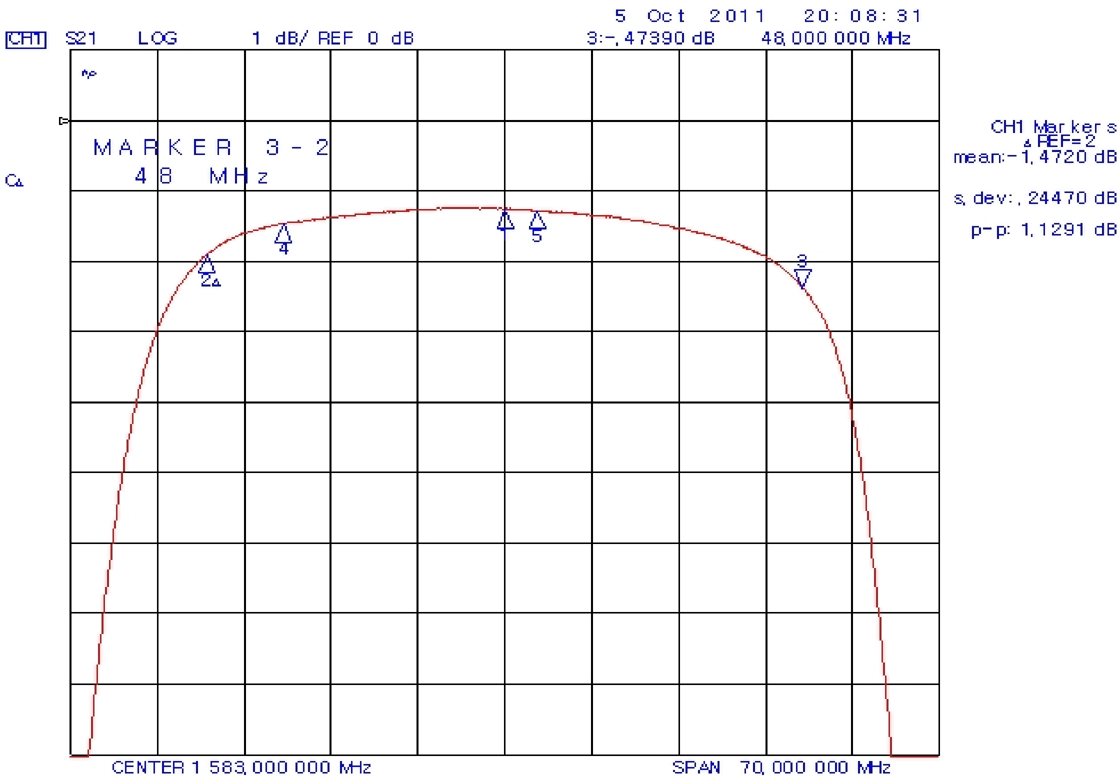
## 4. PLOT DATA (@ 40°C)

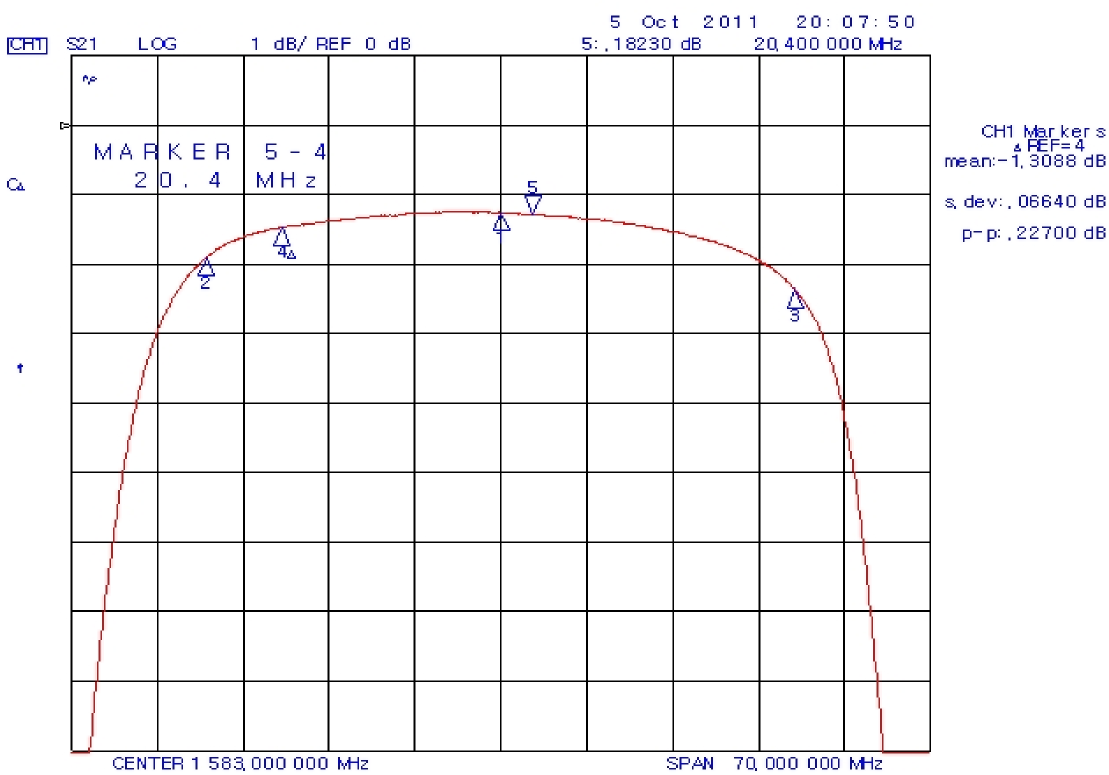


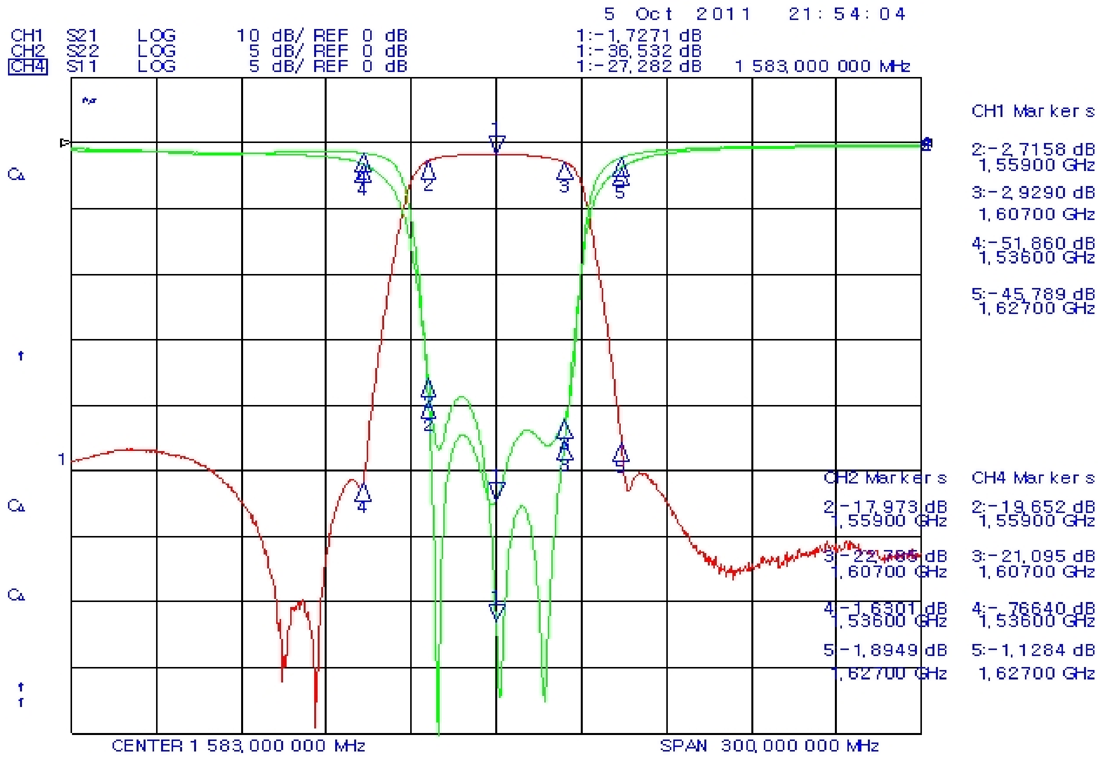

5 Oct 2011 20:08:55
CH1 S21 DEL 10 ns/ REF 0 s
3: 5.8427 ns 48.000 000 MHz
MARKER 3 - 2
48 MHz
Smo
Cor
CH1 Markers
REF=2
mean: 23.918 ns
s.dev: 3.8923 ns
p-p: 16.798 ns
CENTER 1 583.000 000 MHz
SPAN 70.000 000 MHz

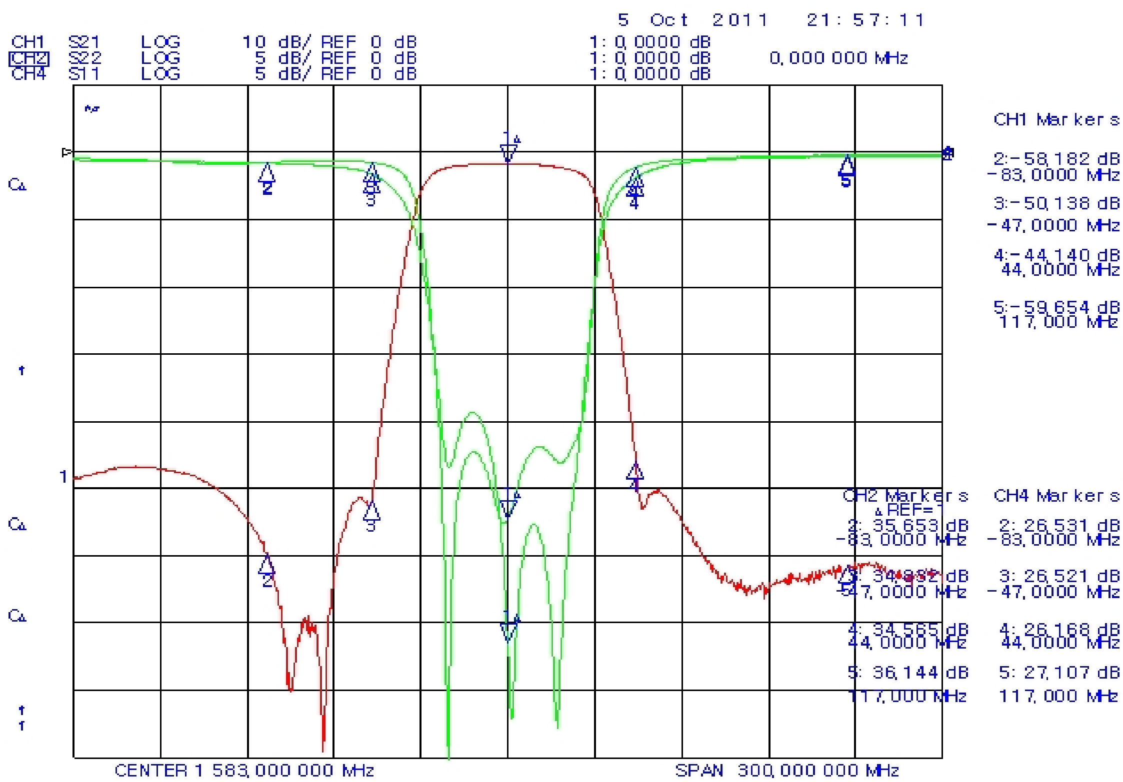

5 Oct 2011 20:09:16
CH1 S21 DEL 10 ns/ REF 0 s
5:-3.8297 ns 20.400 000 MHz
MARKER 5 - 4
20.4 MHz
Smo
Cor
CH1 Markers
REF=4
mean: 21.298 ns
s.dev: 1.1021 ns
p-p: 4.4223 ns
CENTER 1 583.000 000 MHz
SPAN 70.000 000 MHz

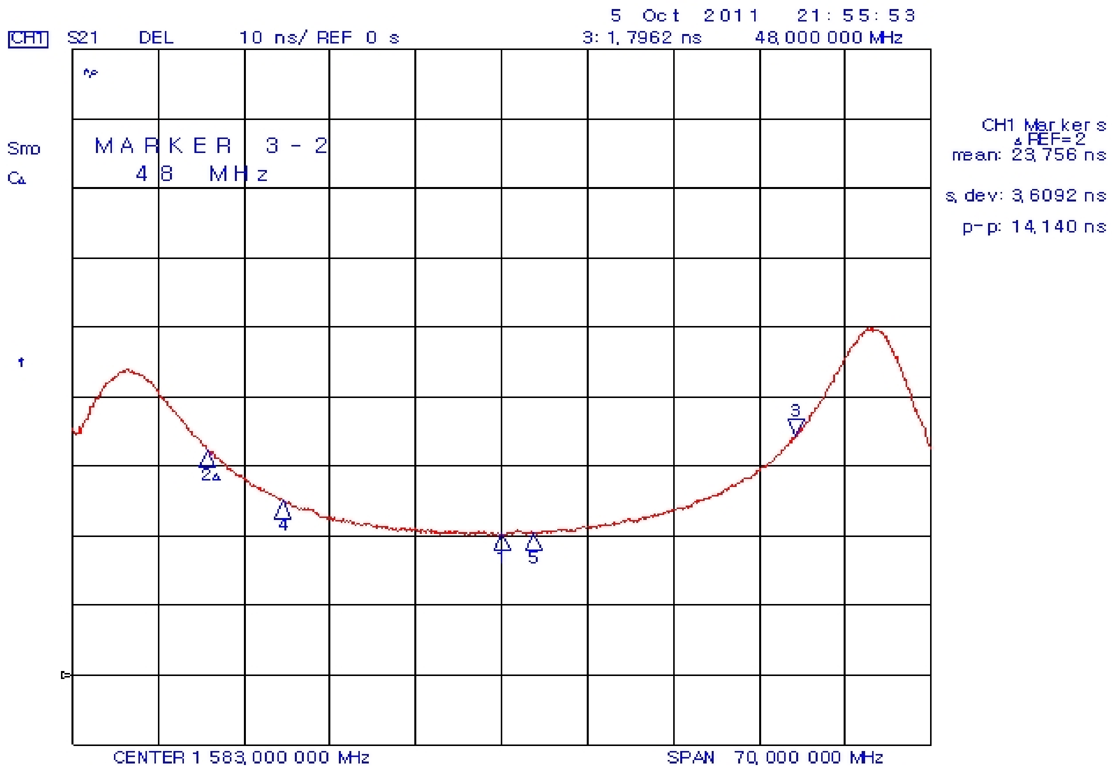

5 Oct 2011 20:08:31
CH1 S21 LOG 1 dB/ REF 0 dB 3:-.47390 dB 48.000 000 MHz
MARKER 3 - 2
48 MHz
CH1 Markers
▵REF=2
mean:-1.4720 dB
s.dev:.24470 dB
p-p: 1.1291 dB
CENTER 1 583.000 000 MHz
SPAN 70.000 000 MHz

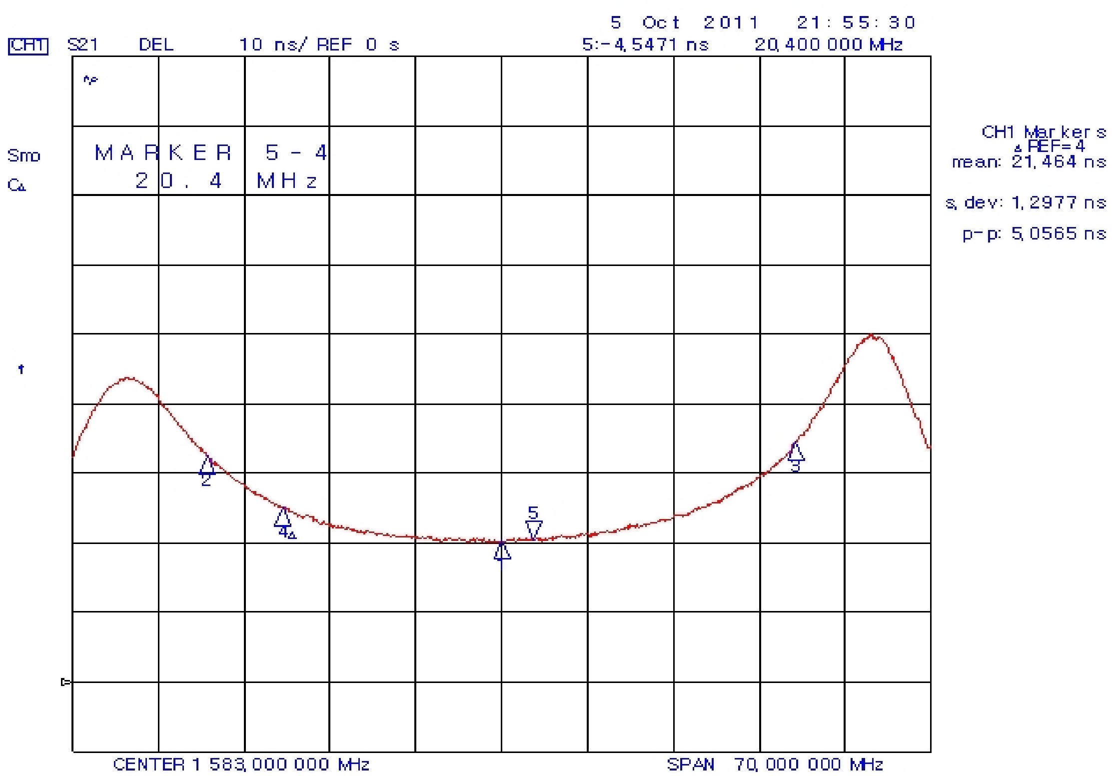

5 Oct 2011 20:07:50
CH1 S21 LOG 1 dB/ REF 0 dB 5:.18230 dB 20.400 000 MHz
MARKER 5 - 4
20.4 MHz
CH1 Markers
▵REF=4
mean:-1.3088 dB
s.dev:.06640 dB
p-p:.22700 dB
CENTER 1 583.000 000 MHz
SPAN 70.000 000 MHz

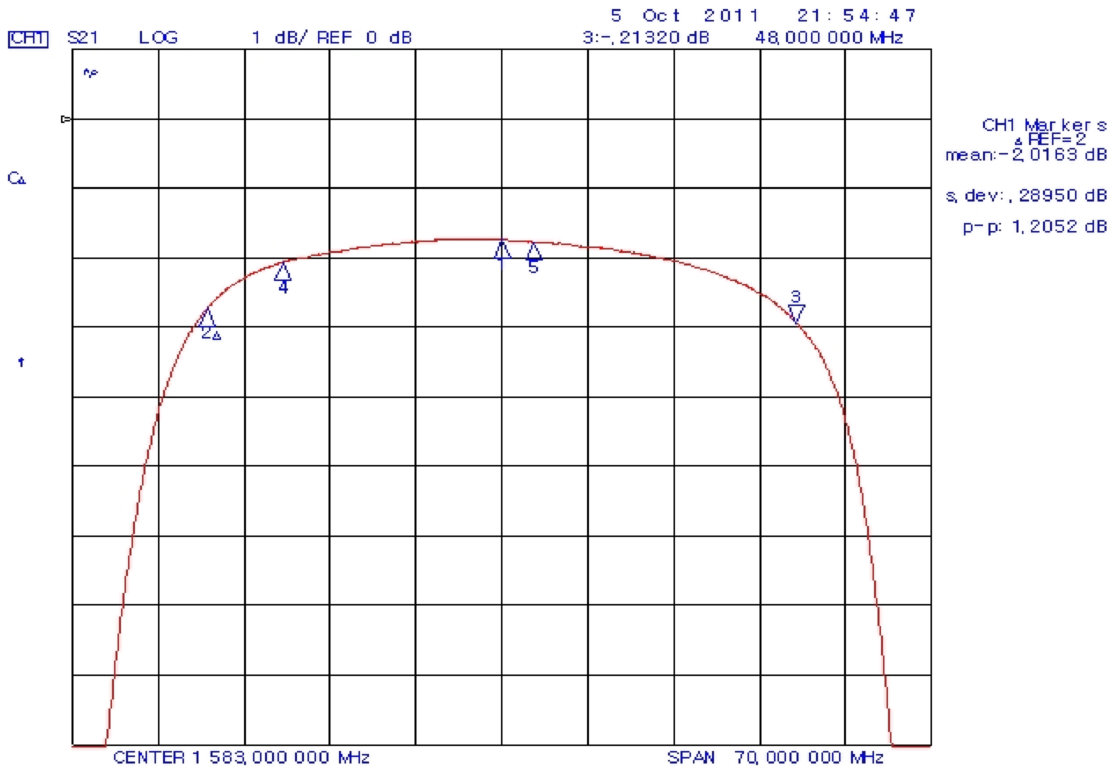
## 5. PLOT DATA (@ +85°C)

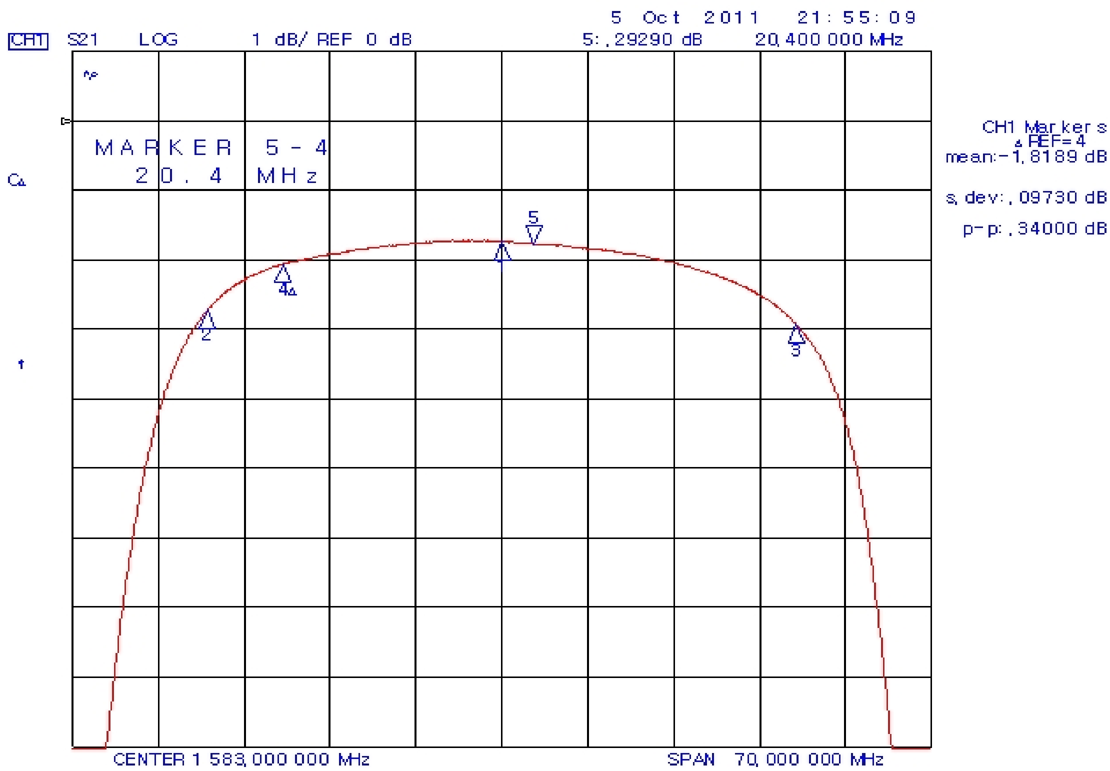



5 Oct 2011 21:55:53
CH1 S21 DEL 10 ns/ REF 0 s 3: 1.7962 ns 48.000 000 MHz
MARKER 3 - 2
48 MHz
Smo
CH1 Markers
REF=2
mean: 23.756 ns
s. dev: 3.6092 ns
p-p: 14.140 ns
CENTER 1 583.000 000 MHz
SPAN 70.000 000 MHz


5 Oct 2011 21:55:30
CH1 S21 DEL 10 ns/ REF 0 s 5:-4.5471 ns 20.400 000 MHz
MARKER 5 - 4
20.4 MHz
Smo
CH1 Markers
REF=4
mean: 21.464 ns
s. dev: 1.2977 ns
p-p: 5.0565 ns
CENTER 1 583.000 000 MHz
SPAN 70.000 000 MHz


5 Oct 2011 21:54:47
CH1 S21 LOG 1 dB/ REF 0 dB
3:-,21320 dB 48,000 000 MHz
CH1 Markers
Δ REF=2
mean:-2,0163 dB
s, dev:,28950 dB
p-p: 1,2052 dB
CENTER 1 583,000 000 MHz
SPAN 70,000 000 MHz

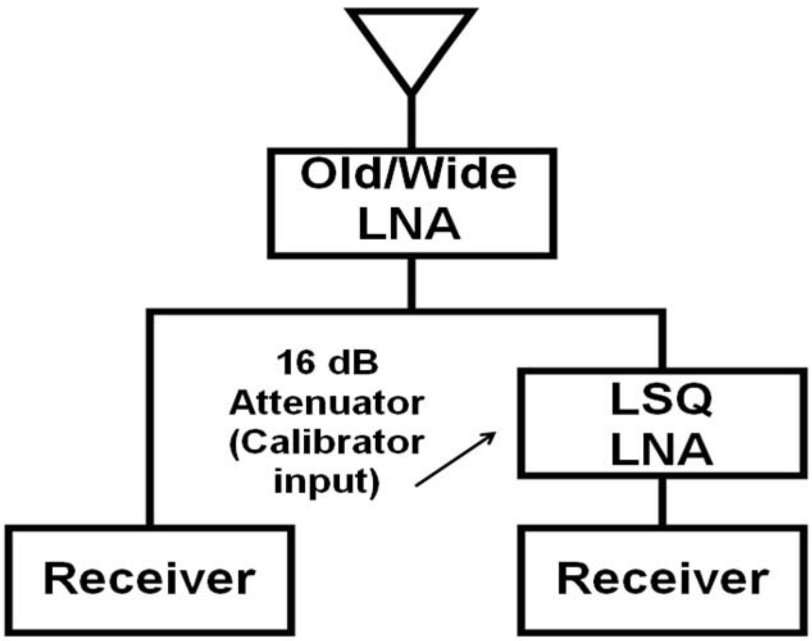

5 Oct 2011 21:55:09
CH1 S21 LOG 1 dB/ REF 0 dB
5:,29290 dB 20,400 000 MHz
MARKER 5-4
20.4 MHz
CH1 Markers
Δ REF=4
mean:-1,8189 dB
s, dev:,09730 dB
p-p:,34000 dB
CENTER 1 583,000 000 MHz
SPAN 70,000 000 MHz

## Attachment C-2

## Javad's Zero Baseline Tests comparing performances of modified and unmodified high precision GNSS antenna

A zero-baseline test was performed by Javad GNSS to test if the incorporation of the additional preselector filters in the modified degraded its performance relative to an unmodified antenna. The test set up is shown in Figure C-2.1 below. The position was calculated using signals coming directly from the unmodified wideband antenna as well as after undergoing the additional filtering in the modified, constrained bandwidth antenna. A 16 dB attenuator was used to reduce the signal power at the input to the modified antenna (output of the unmodified antenna) to the same level as at the input to the unmodified antenna. The advantage of the zero-baseline test set up is that propagation channel variations between the signals fed to the two receivers are completely eliminated.

**Figure C-2.1 Zero-Baseline test to determine the effect of filtering on position accuracy**




The results are shown below in Figure C-2.2

**Figure C-2.2 Zero Baseline Test Results**

| Zero Baseline Results (Carrier Phase), cm | | |
|---|---|---|
| Calibrator | Off | On |
| GPS L1 | 0.02 | 0.02 |
| GPS L2 | 0.01 | 0.01 |
| GLN L1 | 0.39 | 0.14 |
| GLN L2 | 0.01 | 0.01 |

| Zero Baseline Results (Code Phase), cm | | |
|---|---|---|
| Calibrator | Off | On |
| GPS P1 | 4.22 | 4.86 |
| GPS P2 | 5.73 | 4.08 |
| GLN P1 | 60.36 | 7.38 |
| GLN P2 | 2.03 | 1.36 |

The results show the position difference between the two receivers. The "calibrator" refers to the self-calibration (group delay equalization) capability of the receiver. The results show that, even for high precision receivers, where the position estimate is based on carrier phase, the difference between the two receivers is less than 0.2 mm. For the lower precision, code-phase based receivers, the error is also quite small (less than 5 cm) by the standard of such receivers. Furthermore, it is clear that group delay equalization, where advantageous, is not necessary to achieve the above accuracies for CDMA based GPS signals. The group delay equalization is more useful for the GLONASS (GLN) signals, which are of the FDMA type.

## ATTACHMENT 1

## DECLARATION OF SANTANU DUTTA, Ph.D.

I, Dr. Santanu Dutta, make the following declaration.

1. I am Senior Vice President of Radio Access Technologies and Chief Engineer of LightSquared Inc. ("LightSquared").

2. I am the technically qualified person responsible for the technical and engineering information contained in the foregoing Technical Appendix. I have either prepared or reviewed that information and certify that to the best of my knowledge and belief it is truthful and accurate.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on March 15, 2012.

Santanu Dutta

Santanu Dutta

**DECLARATION OF JEFFREY J. CARLISLE**

I, Jeffrey J. Carlisle, hereby make the following declarations under penalty of perjury.

1. I am Executive Vice President, Regulatory Affairs and Public Policy of LightSquared Inc. ("LightSquared"). In that capacity, I am responsible for all domestic and international regulatory and policy matters on behalf of LightSquared, including those at the FCC.

2. I have reviewed the foregoing "Comments in Opposition of LightSquared Inc.", and certify that, to the best of my knowledge and belief, the factual assertions in that pleading are truthful and accurate.

/s/ Jeffrey J. Carlisle
Jeffrey J. Carlisle

Executed: March 16, 2012

**DECLARATION OF SANTANU DUTTA**

I, Santanu Dutta, hereby make the following declarations under penalty of perjury.

1. I am Senior Vice President, Radio Access Technologies and Chief Engineer of LightSquared Inc. ("LightSquared"), and am the technically qualified person responsible for the technical aspects of the foregoing "Comments in Opposition of LightSquared Inc."

2. I am familiar with Part 25 of the Commission's rules, and have either prepared or reviewed the engineering information submitted in this pleading. To the best of my knowledge and belief, the engineering information presented therein is complete, truthful, and accurate.

/s/ Santanu Dutta
Santanu Dutta

Executed: March 16, 2012